GHL CONSULTANTS LTD

Read Jones Christoffersen Consulting Engineers

Building and Safety Policy Branch
Ministry of Housing and Social Development
Amending the BC Building Code to Permit up to and including 6 Storeys of Wood-Frame Buildings of Residential Occupancy

Stage 1 Report
Building Code Provisions for Residential Buildings and Identification of Technical and Process Risks

October 29, 2008

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SUMMARY

Stage 1 Report - Building Code Provisions for Residential Buildings and Identification of Technical and Process Risks

As part of the recent initiative to amend the current BC Building Code (BCBC) to permit up to and including 6 storeys of wood-frame buildings of residential occupancy, GHL Consultants Ltd (GHL) and Read Jones Christoffersen Ltd (RJC) have been requested by the Building and Safety Policy Branch of the Ministry of Housing and Social Development to prepare the following technical report aimed at identifying and addressing technical issues with respect to the proposed Code change. In this Stage 1 report, a summary of the current BCBC provision for residential buildings relating to fire safety, structural and building envelope is provided, and the technical and process risks related to the proposed Code change are identified.

The acceptable solution in Division B, Part 3 currently does not permit combustible buildings of residential occupancy in excess of 4 storeys. Division B, Part 4 and Part 5 for structural and building envelope requirements do not currently restrict height of combustible buildings. Therefore, from a technical risk perspective, the primary concern in limiting combustible buildings to 4 storeys is due to Division B, Part 3 limitations.

Based on GHL and RJCs research, technical and process risks with respect to the Code change proposal are identified. It is identified that, generally, the technical risks are not likely to increase, while there are a number of issues relating to process risks that should be addressed prior to the Code change. These issues relate largely to the readiness of the construction industry in general in delivering a 5 or 6 storey wood-frame building that is in compliance with the Code as well as of good engineering practice. Key recommendations for addressing the process risks are provided in this report.

The Stage 2 report to be released in October will further identify the Code change recommendations, and recommendations to changing or adding technical standards and guidelines relating to construction of 5 or 6 storey wood-frame buildings, though some of these recommendations are identified in this Stage 1 report.

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ABBREVIATIONS

AHJ	Authority Having Jurisdiction
AIBC	Architectural Institute of British Columbia
APEGBC	Association of Professional Engineers and Geoscientists of British Columbia
BC	British Columbia
BCBC	British Columbia Building Code
BCIT	British Columbia Institute of Technology
BEEP	Building Envelope Education Program
BEP	Building Envelope Professional
BSPB	Building and Safety Policy Branch
CANCEE	Canadian National Committee on Earthquake Engineering
CMHC	Canada Mortgage and Housing Corporation
CP	Certified Professional
CAN/ULC-S101	Fire Test Standard "Fire Endurance Tests of Building Construction and Materials"
CSA	Canadian Standards Association
CSA O86	CSA Standard "Engineering Design in Wood"
EWP	Engineered Wood Product
FRR	Fire-resistance rating
GHL	GHL Consultants Ltd
Group C	Residential occupancy as defined in the 2006 BCBC
GWB	Gypsum wallboard
HPO	Homeowner Protection Office
IRC	Institute for Research in Construction
NBCC	National Building Code of Canada

NFPA	**National Fire Protection Association**
NFPA 13	**NFPA Standard "Installation of Sprinkler Systems"**
NRC	**National Research Council**
OSB	**Oriented Strand Board**
RJC	**Read Jones Christoffersen Ltd**
SEABC	**Structural Engineers Association of British Columbia**
STC	**Sound Transmission Class**
Struct.Eng	**Designated Structural Engineer**
UBC	**University of British Columbia**
ULC	**Underwriter's Laboratory of Canada**
ULC-S101	**Fire Test Standard "Fire Endurance Tests of Building Construction and Materials"**

DISCLAIMER

This technical report is prepared by GHL and RJC for the Ministry of Housing and Social Development. The purpose of this report is to provide a professional opinion to the Ministry on the proposed Code change to permit up to and including 6 storey wood-frame buildings of residential occupancy. The formulation of GHL and RJC's opinion is based on the science of fire, structural and building envelope engineering, review of the available literature and preliminary consultation which are inherently limited by the short timeframe (August 15, 2008 – September 5, 2008). The work of this report is limited by the timeframe, which would normally require substantial research for a significantly greater duration. The work as presented in this report is based on GHL and RJC's knowledge as competent practitioners in their respective fields. GHL and RJC's work shall not be construed as exhaustive. There may be other relevant considerations for the Code change proposal not identified by GHL and RJC. At time of report writing GHL and RJC have recommended BSPB to retain qualified professionals to address other requirements such as including but not limited to construction fire safety, as well as electrical and mechanical systems of building design. Additionally, it is assumed that a public consultation process is being carried-out in conjunction with this report. The BC Government shall be solely responsible for the act of amending the BC Building Code to permit up to and including 6 storeys of wood-frame buildings of residential occupancy, or making any changes to any provisions in the Building Code. It is the BC Government's sole discretion to adopt, consider or accept in part or in full the work of GHL and RJC contained in this report. GHL and RJC shall not be responsible for any loss of any kind that may arise due to any construction, building, or structure as a result of GHL and RJC's work or any Building Code or construction regulation change in British Columbia, or anywhere. Should this report be made available to other organizations that have regulatory capacity in construction of buildings and structures for anywhere this disclaimer shall equally apply. By preparing this report GHL and RJC do not express explicitly or implicitly any social, economical or political opinion, or any other non-technical opinion, as it relates to the Code change proposal. This report is intended to be purely technical in nature. Any inquiries on this report shall be directed to the Ministry:

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1.0 BASIS OF REPORT

1.1 Stage 1 Report

As part of the recent initiative to amend the current BC Building Code (BCBC) to permit up to and including 6 storeys of wood-frame buildings of residential occupancy, GHL Consultants Ltd. (GHL) and Read Jones Christoffersen Ltd. (RJC) have been requested by the Building Safety and Policy Branch (BSPB) of the Ministry of Housing and Social Development to prepare the following technical report aimed at identifying and addressing technical issues with respect to the proposed Code change. It is anticipated that the report will be issued in 3 stages summarized as follows:

- **Stage 1** Summarize current Code provisions with respect to residential buildings and identify the technical and process risks with the Code change.
- **Stage 2** Provide a proposal outlining the Code change.
- **Stage 3** Provide a finalized report that incorporates input and comments from stakeholders that reviewed the Stage 1 and Stage 2 reports.

This report is the Stage 1 report. The purpose of this report is to provide a summary of the existing Code provisions for buildings of residential occupancy and identify key technical and process risks that may result due to the Code change.

The objective of this Report is to provide the following:

- A summary of the Code provision for residential buildings with respect to fire safety, structural, and building envelope requirements.
- Identification of technical and process risks associated with the Code change focusing on fire safety, structural and building envelope issues.
- Preliminary comments on approach to addressing technical and process risks.

1.2 Role of GHL and RJC

The role of GHL and RJC as consultants to BSPB is to identify, to the best of our professional knowledge, fire safety, structural and building envelope issues relative to the proposed Code change as specifically requested by BSPB. The sole purpose of GHL and RJC's work is to provide the BC Government our opinion on 5 and 6 storey combustible buildings of residential occupancy should it become permitted in BC. GHL and RJC are retained to address conventional wood-frame construction typical in BC; we have not been retained to address any other types of combustible construction.

1.3 Role of the BC Building Code

The BCBC is the Building Code for British Columbia, except Vancouver where it is governed by the Vancouver Building Bylaw. The BCBC is the regulation that governs building construction in BC. The 2006 BCBC is the edition of the BCBC currently in effect, and it is an objective-based Building Code. Code compliance with the 2006 BCBC is achieved by demonstrating compliance with the Code objectives. It is noted that the design of a technically sound building depends upon many factors beyond simple compliance with the Building Code. The 2006 BCBC has the following five broad objectives, which are further refined into specific objectives that translate into Code requirements:

- Safety
- Health
- Accessibility for persons with disabilities
- Fire protection of building and facilities
- Energy

As an objective-based Code, the 2006 BCBC provides two avenues for Code compliance. One is prescriptive through meeting the acceptable solutions in Division B. The other is by alternative solutions, which often requires technical substantiation to demonstrate that a proposed design will achieve a level of performance that meets the minimum required by the Building Code. Division A Appendix A-1.2.1.1.(1)(a) and (b) further clarifies Code compliance via acceptable solutions and via alternative solutions.

As an objective-based Code, the BCBC does not restrict the design and construction of a building to the acceptable solutions. The Code provides an opportunity to achieve Code-compliance through alternative solutions should it be desired. It is known that 5 and 6 storey wood-frame buildings have been built previously under equivalencies and alternative solutions, often as a "podium" structure where the first storey is noncombustible of commercial use and the remaining being residential wood-frame.

However, in the absence of an acceptable solution in Division B to specifically recognize 5 and 6 storey combustible buildings, designers and AHJs alike are not given a clear basis for the design and review of such buildings. This is because the majority of the Code requirements are largely predicated upon the construction Article determined in Subsection 3.2.2., which is determined based on building characteristics including sprinkler provision, building height, building area, and occupancy classification. Therefore, without an acceptable solution to recognize the constitution of 6 storey combustible buildings, it is difficult for designers and AHJs to justify such building, as well as any related alternative solutions, because it is difficult if not impossible to provide an analysis for a design not specifically defined in Division B.

1.4 Public Interest Decision

Changing the Building Code is a public-interest decision. The BCBC has been changed and revised since its first enactment in 1973. The act of enacting and revising the Building Code is defining the acceptable minimum level of performance for buildings in British Columbia. Risk is generally defined as the product of probability of failure and the consequences. Division B of the Building Code defines the boundaries between acceptable risk and the "unacceptable" risks referred to in the statements of the Code objectives. That is, any risk remaining once the applicable acceptable solutions in Division B have been implemented represents the residual level of risk deemed to be accepted by the broad base of British Columbians who have taken part in the consensus and legislative processes used to develop the BCBC. Therefore, by changing the Building Code to permit up to and including 6 storeys of wood-frame buildings of residential occupancy, it is an act to acknowledge and accept risks associated with the Code change.

1.5 Methodology

GHL and RJC were formally requested by BSPB to prepare the Stage 1 report on August 15, 2008, with a given timeframe of 3 weeks. The work of GHL and RJC as presented in this report is based primarily on our professional experience as well as review of key literature possible during the 3 week timeframe, as well as incorporation of input from key stakeholders from the Technical Advisory Group and Stake Holders' meetings held in September 2008. During the time of report writing, we also conducted consultation with key stakeholders for the purpose of establishing the technical and process risks that are identified in this report. Organizations that we have consulted include:

- City of Vancouver, Office of the Chief Building Official
- Resort Municipality of Whistler, Permit and Licensing Department
- FPInnovations Forintek Division
- Homeowner Protection Office
- National Home Warranty
- Travelers Guarantee Company of Canada
- Lombard Canada
- Building and Safety Policy Branch
- Structural Engineers Association of British Columbia

GHL and RJC have also reviewed the joint AIBC and APEGBC letter submitted to BSPB regarding technical considerations for the proposed Code change.

1.6 Assumptions

Combustible Construction

The work presented in this report assumes traditional wood-frame construction employed in BC as requested by the Ministry. This assumption is consistently used with respect to structural and building envelope discussion in this report as the respective Parts of the Code are more specific on the type of material and construction technique. However, with respect to Part 3 of Division B, the term "combustible construction" is used as the Code requirements in Part 3 are founded on the basis of combustible versus noncombustible construction materials, notwithstanding that the typical combustible construction in BC is wood-frame construction as limited by other Codes, standards and engineering requirements outside of Part 3 of Division B. The terminologies "combustible construction" and "wood-frame" can generally be considered as interchangeable; except with respect to fire safety, it should be noted that combustible construction could potentially include other types of combustible material through alternative solutions and that GHL and RJC have only been retained to address wood-frame construction.

Scope of Code Change

The work also assumes changing the Building Code with respect to fire safety, structural and building envelope requirements in Division B, Part 3, Part 4 and Part 5, respectively. GHL and RJC have not been requested to provide work relating to any other aspect of the Building Code outside of Parts 3, 4 and 5 of Division B, as well as construction fire safety. It is noted that other requirements, such as occupant safety due to building usage and accessibility, as well as health requirements contained in Part 3 of Division B, are not part of the scope of GHL's work.

It is assumed that the proposed 5 or 6 storey wood-frame building will not be a high building as defined in the Building Code. High buildings imply significantly more complex firefighting techniques which are outside the scope of this report. High buildings are defined in Division B, Clause 3.2.6.1.(1)(d) as buildings with the uppermost floor level is more than 18m above grade.

The authors also recognize that there are issues relating to the aging population and difficulty of evacuation; however, this is a separate topic applying to all buildings, combustible or noncombustible, not just 5 and 6 storey wood-frame buildings.

Alternative Solutions

This report relates to accepted solutions of Division B of the Code. This report is not intended to preclude Alternative Solutions to address elements outside the scope of this report, or different solutions to that provided in Division B. For example, this report is not intended to preclude Alternative Solutions for highrise buildings or other occupancies; it simply recommends Code changes in Division B to facilitate 5 and 6 storey wood-frame residential buildings.

2.0 CODE PROVISIONS FOR RESIDENTIAL BUILDINGS

2.1 Fire Safety

The 2006 BCBC permits both combustible and noncombustible construction for buildings of residential occupancy. In general, there are 3 categories of Group C (residential) buildings provided in Subsection 3.2.2. as summarized below:

1. Combustible Construction, Up to 4 Storeys, 1 Hour FRR, Sprinklered
2. Noncombustible Construction, Up to 6 Storeys, 1 Hour FRR, Sprinklered
3. Noncombustible Construction, Unlimited Height and Area, 2 Hour FRR, Sprinklered

Currently, combustible construction is limited to 4 storeys while noncombustible buildings are permitted up to 6 storeys if the building is 1 hour fire rated, and unlimited if it is 2 hour fire rated. The assumption is that in large buildings (i.e., those permitted with unlimited height and area), 2 hour FRR is necessary in terms of addressing lengthier evacuation process and fire service response. For 1 hour rated buildings, the assumption is that the performance of 1 hour FRR is appropriate for evacuation and rescue operations based on the limitation placed on building area and height. For this reason, this report does not envision high buildings as defined in the Code.

The general concern with combustible construction is that combustible material may be exposed to and subsequently support the growth of fire. Therefore, not only would the integrity of the combustible construction be affected by fire, the construction material itself may also become a source of fuel. There is also a significant concern with fire spread within combustible void spaces. This is particularly true with balloon-framing techniques that were popular in the early 1900's; however, much of this has been addressed through fire blocking and fire stopping requirements in the Building Code. In terms of understanding the origin of the building height and area limitations on combustible buildings it is necessary to conduct a brief review the history of this part of the Building Code.

Prior to the 1900's, there was no national or provincial Building Code or government-based regulatory framework for construction of buildings in Canada. Buildings were generally built to meet the safety requirement of insurance underwriters. In BC, combustible buildings of 5 and 6 storeys are known to have been built during this time and some are still in existence today. The first edition of NBCC was introduced in 1941. In BC, it was used as the model Code for municipal building bylaws until the first province-wide Building Code enacted in 1973. The 1973 BCBC adopted the 1970 NBCC. Although the BCBC has since been changed about every 5 years in synchronization with the NBCC Code change cycle, much of the prescriptive requirements of the Code have remained unchanged as the fundamental principles of fire engineering have not changed since the first edition of the NBCC.

Combustible buildings were originally limited to two storeys and of residential occupancy and have subsequently been limited to 3 storeys since the 1965 NBCC. Note that in the 1965 NBCC the term "combustible" building was specifically used in Part 3 and that there is no specific reference to "wood-frame" in this Part, although wood-frame is the typical combustible building in BC. In terms of BCBC, combustible residential buildings have been limited to 3 storeys since the 1973 edition (1970 NBCC). The building height limitation is in recognition of the risks associated with combustible construction. The Code also limited building area based on (a) the number of storeys (b) the number of streets the building faces and (c) whether the building is sprinklered. In general, with increasing building height, the permitted building area is decreased; with increasing number of streets the building faces, the permitted building area is increased. These two factors largely reflect the ease of accessing the building for emergency response purposes. Finally, by sprinklering the building, the Code allowed doubling the area permitted in the unsprinklered building area limits. This is to recognize the advantage of sprinklers in many aspects of building fire safety. As summarized in Table 1, for a sprinklered 3 storey building of residential occupancy, the permitted building area for combustible construction is 15% of that permitted for noncombustible construction.

Table 1
Summary of sprinklered 3 storey buildings of residential occupancy permitted under the 1970 NBCC. The unit for area is square foot in the 1970 NBCC; the values in this table have been converted and rounded to metric.

	Building Area			**Fire-Resistance Rating**
	Facing 1 Street	Facing 2 Street	Facing 3 Street	
a. Combustible 3 storey	$1080m^2$	$1350m^2$	$1620m^2$	1 hour
b. Noncombustible 3 storey	$7200m^2$	$9000m^2$	$10{,}800m^2$	1 hour
% = a / b	15%	15%	15%	

There is limited justification for the building height and building area values prescribed in the 1970 NBCC. Similarly, there is also no apparent justification for the selection of the 15% as the ratio for permitted building area between combustible and noncombustible construction. Despite that the figures were selected with limited technical justification, it is most likely that the values made social sense in terms of the practical needs of residential buildings at the time, and taking into consideration the fire safety prospects of the buildings in terms of fuel load, occupant load and firefighting capabilities as they relate to building height and area. The 3 storey combustible residential construction article remained essentially unchanged until the 1985 NBCC, though in the 1980 NBCC, the building areas were converted to metric, for which the building areas were slightly increased.

The Code has traditionally recognized the effectiveness of sprinkler protection, and has permitted a doubling of allowable building area. However, there appears to be no rationale for the 'doubling'. Given that sprinklers increase the level of fire safety in a building dramatically, controlling between 70% and 98% of all fires[1] (depending on the analysis and degree of monitoring and supervision), the selection of doubling seems arbitrary and probably conservative. For example, there seems to be no logical reason why the allowable building area was not quadrupled. It is significant that with the introduction of monitoring and supervision of sprinkler systems, increasing the reliability from approximately 70% to between 95% and 98%, there was a relaxation on all unoccupied roof fire ratings, but no commensurate increase in allowable building area. As discussed below, the increase from 3 storeys to 4 storeys in the 1990 NBCC (adopted as 1992 BCBC) was clearly in part predicated on the effectiveness of sprinklers, but it is not evident why the increase was limited to 4 storeys.

In the 1990 NBCC, the category "Residential Buildings, 4 Storeys, Sprinklered" was first introduced as Article 3.2.2.36. in the Code. The building placed a building area limitation based on the number of storeys as well as the number of streets the building faces; this was later revised in the 1995 NBCC to be based on the building height only in view of the mandatory sprinkler requirement in this Article. The 4 storey combustible building of Group C occupancy remained unchanged to the current 2006 BCBC. The Code change justification for introducing 4 storey combustible buildings in the 1990

[1] Richardson, J.K., 1985, "The Reliability of Automatic Sprinkler Systems", NRC, http://irc.nrc-cnrc.gc.ca/pubs/cbd/cbd238_e.html, last accessed October 9, 2008.

NBCC is probably one of the few technical justifications on building height and area released by NRC. The document entitled "National Building Code of Canada 1985 - Third Series of proposed Changes" dated August 1988 provides the justification for moving from 3 to 4 storeys in 'Proposed Change No. 3-30'. Proposed Change No. 3-30 states in summary:

- The 1985 NBCC recognizes the safety of 1 hour rated construction for noncombustible buildings of up to 6 storeys.
- In view of the fact that the basic tests for fire-resistance rating are not predicated on the type of construction but are performance based, it was considered that the increase in height from 3 to 4 storeys for combustible buildings but whose area would be approximately 20 per cent of that for a noncombustible building is a conservative approach.
- Consideration is also based on the model Codes in the US which permits 4 storey residential buildings to be constructed with 1 hour rated wood-frame construction. Studies of the fire death rate in multi-family residential buildings in the US indicate that it is very low and that wood-frame construction has not been identified as a problem.

As clarified by Proposed Change No. 3-30, it is evident that NRC had considered the technical risk with respect to moving from 3 to 4 storeys. The change was made based on the 20% ratio between the building area of combustible and noncombustible building, which was viewed as being conservative, as well as the statistics from the US for such type of buildings. The commentary further acknowledges that the fire-resistance rating is a performance measure of building material's endurance in a fire and that the rating is not predicated on whether the material is combustible or noncombustible. In essence, NRC recognized that a 4 storey combustible building built in full compliance with the Code will provide the same performance in a fire as a 4 storey noncombustible building. However, in addressing the risks of using combustible material, the 20% ratio was selected, which was determined as appropriate. The Code change commentary specifically states the conservativeness of this approach and does not indicate limitation on applying the 20% ratio for higher combustible buildings. The new Article 3.2.2.36. in the 1990 NBCC also included two significant changes:

- The ratio between the permitted building area for combustible and noncombustible construction increased from 15% when the building was 3 storeys under earlier editions of the NBCC to 20% for 4 storeys building in the 1990 NBCC.
- Sprinklers became a mandatory requirement for 4 storey combustible buildings of Group C occupancy, whereas it was optional in the 3 storey combustible building of Group C occupancy in earlier editions of the NBCC.

The increase for the ratio from 15% to 20% is likely due to recognition of sprinkler systems; however, this was not explicitly stated in Proposed Change No. 3-30 in the Code change documents.

Clearly, it appears that there is no technical justification for the selection of 15% or 20% ratios noted. There is also no justification for the building heights and areas limits that were established when the NBCC was first written. But similarly, there is also no justification to argue the contrary; that is, based on the performance of the combustible buildings that have been built since the 1900s, they have generally been found to be acceptable. In effect, the BCBC as it has evolved to its current state represents the level of risk that the public may have been arbitrary subjected to, but has since been and is willing to continue to tolerate and accept in BC.

In the 1998 BCBC for sprinklered buildings, the requirements for large buildings to face more than one street and the 9m limitation to the uppermost floor for 4 storey combustible buildings were removed. The Code change from the 1992 BCBC further recognized the increasing acceptance of interior fire fighting for sprinklered buildings.

Table 2 presents a comparison between the 3 categories of residential buildings permitted in the 2006 BCBC as noted in the beginning of this section.

Table 2
A comparison of the 3 categories of residential buildings permitted in the 2006 BCBC. The building area permitted in Article 3.2.2.45. for a combustible building is 20% of that permitted under 3.2.2.43 for a 4 storey noncombustible building. See also schematic illustration in *Appendix A*.

Article	Bldg Height	Bldg Area	Sprinkler	FRR of Floor and Structure	Construction
3.2.2.42.	Unlimited	Unlimited	Yes	2 hour	Noncombustible
3.2.2.43.	6 Storeys	6000m^2	Yes	1 hour	Noncombustible
	4 Storeys	9000m^2			
3.2.2.45.	4 Storeys	1800m^2	Yes	1 hour	Combustible

2.2 Structural

Under the current 2006 BCBC which is based on the 2005 NBC, structural requirements are covered under Part 4 of Division B. There are few limitations in this section with respect to the maximum building height that can be constructed with conventional wood framing. It was always well understood by the structural engineer that the limitation on building height was generally due to requirements related to the fire and one did not need to consider the potential challenges of building taller wood structures under Canadian Codes. Thus, as the wood industry for residential building evolved, Building Code provisions were made based on the type of residential structures that were being built and how they performed. And for years now, our experience has generally been limited to the performance of wood structures up to 4 storeys in height.

In conjunction with the Building Codes, material Codes such as wood, steel and concrete evolve such that each Code is coordinated and can be used in conjunction with Part 4 of the specific referenced Building Code. As Building Codes evolve and change, the committees of material Codes are required to closely review and react to the changes in new Building Codes such that the material Codes can be applied to reflect the requirements of the Building Code. Each material Code is updated and revised such that they are coordinated with and can be referenced to the current Building Code.

For wood, the building and material Code provisions to date have evolved based on the past experience and performance of wood-frame buildings up to 4 storeys in height. Past experience has shown that the Code provisions have generally led to buildings that are safe. More recently, material Codes have shifted to reliability based design to increase the uniformity of safety for all building materials. For wood, reliability based design coupled with extensive research and testing has generally resulted in higher capacities for wood with less conservatism in design. From previous to current Codes, wood capacities have tended to perform well within residential structures up to 4 storeys. However, there are other factors which impact the capacity of wood which are inherent in the nature of the material. Construction practices, workmanship, detailing, field reviews, the effects of other materials which may add strength, types of systems (i.e., seismic systems, wall systems, floor systems, etc), and shrinkage to name a few all have an impact on the capacity of wood and are not dealt with effectively by Code provisions. These factors can all have an adverse effect on the capacity of wood elements which only gets compounded when increasing these structures from 4 to 6 storeys. For example, vertical loads in stud walls and posts will increase 50% in lower floors. Sheathing requirements, notching for electrical and plumbing, load sharing, bearing, and tolerances will all play an increased role in the actual capacities of the walls and posts. Overall shear and moment forces due to wind and seismic activity will increase 50 to 200 percent in lower shear walls where again notching, workmanship, types of systems, shrinkage and details will all effect the strength. The general result will be that the overall safety of these taller and heavier structures will decrease if such inherent factors are not adequately addressed. So it is important to keep in mind that Building Code provisions as well as the wood material Code CSA O86 have evolved based on the performance of wood structures up to 4 storeys in height. The potential structural challenges associated with taller wood buildings have not been addressed as Code provisions for fire have limited wood structure to a maximum of 4 storeys.

From a material capacity point of view, there should be few impediments to allowing wood building to exceed 4 storeys. Wood elements are analyzed and designed with material Code provisions similar to that of other materials such as steel and concrete. Currently, there are a number of counties and districts in the US that allow residential wood building up to 5 storeys in height, and 6 storeys is being discussed. Other countries around the world also have experience with wood buildings higher than 4 storeys, but we must keep in mind, many of the construction practices and forms of construction are not recognized through Canadian standards. So it is important to realize that although there are few technical changes required in the Codes to allow for 6 storey wood buildings, the greatest risks will result from the detrimental effects due to the process risks compounding as the structures become taller and heavier. Furthermore, as the buildings become taller and heavier, the inherent nature realized in conventional wood-frame systems will play a less significant role. Just extrapolating what is currently practiced for 4 storey buildings to 6 storeys is not enough to maintain a uniform level of safety.

As far as Part 4 of Building Code currently stands, the only real limitations on height for wood structures falls under the seismic provisions of Table 4.1.8.9 where maximum height limits for different systems in different seismic zones range between 15m to no limit. As an example, for a typical Vancouver project utilizing nailed wood shear walls, a height limit of 20m would generally be imposed. It may well be that the 15m and 20m limitation in the Building Code will limit the height of wood based lateral systems that can be constructed in some of the higher seismic zones within BC. Proposed changes to these limits are beyond the scope of the BCBC and would only appropriately be considered for revision by CANCEE (Canadian National Committee on Earthquake Engineering) who advises on Part 4 of the NBCC for all seismic provisions.

As far as the wood material Code CSA O86.1 currently stands, the design for ultimate limit states and serviceability limit states is similar to that of steel and concrete and thus should generally not limit the framing systems referenced to 4 storeys. From a technical point of view, providing that a clear load path with elements designed and detailed in accordance with the material Code, there should be few concerns with potentially designing 5 to 6 storey wood buildings. However, there are a number of design considerations lending themselves to good practice that would need to be further explored in consideration of taller wood buildings. These include, but are not limited to items such as:

- Appropriate seismic provisions or guidelines consistent with other material Codes.
- Guidelines providing a level standard of practice for 5 and 6 storey buildings.
- Appropriate workmanship / tolerance guidelines. The effect of workmanship and tolerances will play a larger role in taller wood structures and deserve consideration. Currently, there are no workmanship clauses in the Wood Code.

- Appropriate independent peer reviews for both design documents and reviews during construction.
- Considerations for hybrid structures – wood-frame building with concrete, steel or masonry elements.
- Considerations for shrinkage. Higher building will result in large movements resulting from the drying and shrinkage of wood.
- Consideration for higher lateral loads, movements and potential vibrations due to wind and seismic loads coupled with the effects of shrinkage, workmanship, and types of lateral systems used.

Although some of these considerations may be dealt with through Code provisions, many of them will need to be dealt with through changes to the processes in which these structures are designed, detailed and constructed.

2.3 Building Envelope

The 2006 BCBC [in Division A, 1.3.3.2.(1)(c)] requires the application of Division B, Part 5 "Environmental Separation" for all Group C, *residential occupancies* exceeding 3 *storeys* in *building height*. Division B, Part 5 itself though, does not include any language that explicitly references the height of a building employing a light wood-frame structural system. The history of the development of Part 5 explains the nature of the 'performance based' language within this Part, and the reason that height is not explicitly addressed.

The adoption of an 'objective based' Code structure with the 2005 NBCC (and 2006 BCBC), did not significantly impact the language in Part 5, as it was developed using a 'performance based' approach. In editions of the NBCC prior to 1980, Part 5 was entitled 'Materials', and did not focus specifically on 'building envelope' issues. With the 1980 NBCC (and the subsequent 1985 and 1990 versions, adopted as BCBC in 1981, 1987 and 1992 respectively), Part 5 was renamed "Wind, Water and Vapour Protection", and although quite simple in form and content, outlined minimum necessary performance requirements for the building envelope. The 1995 NBCC (adopted as BCBC in 1998) re-titled Part 5 as "Environmental Separation", and expanded the scope of the described performance requirements. In the 2005 NBCC (and 2006 BCBC) a section on Sound Transmission was moved in to Part 5, which, as an exception to the rest of the Part, is written with prescriptive requirements.

Although Part 5 was created to be a performance Code, reference has often been made in the appendix to the prescriptive requirements in Part 9. In the 1980 through 1990 NBCC, reference was made in appendix note A-5.7.1.1. to the prescriptive requirements in Part 9 as a *"guide for installation of exterior claddings, vapour barriers, thermal insulations, sheathing papers, flashings and fastening devices"* for simpler buildings. In the 1995 NBCC only a comparison is made at A-5.5.1.2.(2) that the Part 5 approach allows more flexibility than the equivalent requirements in Part 9. In the NBCC 2005, with the addition of Section 5.9 Sound Transmission, reference is made at A-5.9.1.1.(1) to tables in Part 9 as a source of values to satisfy the requirements in Part 5, although any other references to Part 9 are gone.

While the more prescriptive sections in Part 9 may make reference to material and system requirements, the same can not be said of Part 5 (aside from the section on sound transmission). Within the performance structure of Part 5, there has never been any explicit language that addresses, or creates any limitations, based on the height of a building employing a light wood-frame structural system.

3.0 RISKS ASSOCIATED WITH CODE CHANGE

3.1 Fire Safety

Section 2.1 presented a summary of the current Code provisions relative to residential buildings of combustible and noncombustible construction. This section presents GHL's preliminary comment on the technical and process risks on fire safety relative to the proposed Code change. The Code change proposal is not part of this report; it will be forthcoming in the Stage 2 Report. However, out of the analysis that has been conducted thus far, it is anticipated under the new Code that a 5 or 6 storey wood-frame building would have the characteristics as presented in Table 3. The characteristics are presented here for discussion purposes.

Table 3
Characteristics of the Proposed Code Change Building.

Characteristic	Proposed	Rationale
Building height	Maximum 6 storeys	▪ Public interest
Building physical height	18m to uppermost storey floor	▪ Technical risk ▪ Building is not a high building
Building area	$1440m^2$ for 5 storeys; $1200m^2$ for 6 storeys	▪ Technical risk ▪ Maintain the 20% ratio to that permitted for noncombustible buildings
Construction material	Combustible	▪ Public interest
Floor and mezzanine FRR	1 hour; 2 layer GWB	▪ Technical risk ▪ Process risk
Loadbearing members FRR	1 hour; 2 layer GWB or 1 layer with heavy timber	▪ Technical risk ▪ Process risk
Sprinkler system	Yes, to NFPA 13 standard	▪ Technical risk
Exterior cladding	Noncombustible or combustible cladding meeting Clause 3.1.5.5.(1)(a) and (b).	▪ Technical risk

TECHNICAL RISKS

Technical risk is defined by BSPB to mean: *exposure to loss arising from activities such as design, engineering, and construction processes and includes the following risk areas: fire safety, seismic, structural shrinkage, sound transmission, building techniques, moisture, material shrinkage, etc.*

In general terms, with respect to fire safety, this can be paraphrased to mean the level of risk associated with a building that is built in full compliance with Division B, Part 3 without significant defect. In terms of fire safety, the technical risk is a measure of the probability for fire to occur and the consequential losses.

In general, based on the effectiveness of a mandatory sprinkler system, it can be easily argued that a sprinklered building is safer than an unsprinklered building. Where a sprinkler system may not suppress a fire, it can generally control the spread and growth of fire such that in conjunction with fire separations required by the Code, will provide a greater level of safety than an unsprinklered building with respect to occupant safety and fire service response. It can be demonstrated that the risk of a sprinklered 6 storey building is less than that of an unsprinklered 3 storey building. With respect to failure of a sprinkler system, this is inherently addressed by limiting the ratio of building area between combustible and noncombustible buildings of the same height to 20%.

In general, it is not possible to provide a quantitative analysis of the technical risk as the creation of the NBCC was not based on a quantitative approach originally. Providing a quantitative analysis based on fire statistics would be impossible as 6 storey combustible buildings do not currently exist in BC. It would also be difficult to draw a reasonable comparison to 6 storey combustible buildings in other countries as the Code and construction practices in other countries may likely be different from that of BC. Therefore, it is necessary to employ a qualitative approach by comparing the risk between a 4 and a 6 storey residential building of combustible construction. A comparison to a 5 storey combustible building is not necessarily needed as the analysis for 6 storeys would include that of 5 storeys.

The technical risks addressed by the 2006 BCBC are described in the Code objectives found in Division A, Section 2.2. "Objectives". The Code objectives define fire safety issues that the Code intends to address. Division B Part 3 is based on fire engineering principles that the Code employs in addressing the objectives prescriptively. The Code objectives relating to fire are as follows:

- **OS1 Fire Safety**
  An objective of [the 2006 BCBC] is to limit the probability that, as a result of the design or construction of the building, a person in or adjacent to the building will be exposed to an unacceptable risk of injury due to fire. The risks of injury due to fire addressed in this Code are those caused by:

  OS1.1 – fire or explosion occurring
  OS1.2 – fire or explosion impacting areas beyond its point of origin
  OS1.3 – collapse of physical elements due to a fire or explosion
  OS1.4 – fire safety systems failing to function as expected
  OS1.5 – persons being delayed in or impeded from moving to a safe place during a fire emergency

- **OP1 Fire Protection of the Building**
  An objective of [the 2006 BCBC] is to limit the probability that, as a result of its design or construction, the building will be exposed to an unacceptable risk of damage due to fire. The risks of damage due to fire addressed in this Code are those caused by:

  OP1.1 – fire or explosion occurring
  OP1.2 – fire or explosion impacting areas beyond its point of origin
  OP1.3 – collapse of physical elements due to a fire or explosion
  OP1.4 – fire safety systems failing to function as expected

- **OP3 Protection of Adjacent Buildings from Fire**
  An objective of [the 2006 BCBC] is to limit the probability that, as a result of the design or construction of the building, adjacent buildings will be exposed to an unacceptable risk of damage due to fire. The risks of damage to adjacent buildings due to fire addressed in this Code are those caused by:

  OP3.1 – fire or explosion impacting areas beyond the building of origin

From the objectives, the following areas of technical risk can be established as summarized in Table 4.

Table 4
Technical risks on fire safety addressed by the 2006 BCBC.

Technical Risk	Code Objective
Ignition	OS1.1, OP1.1
Fire spread beyond point of fire origin	OS1.2, OP1.2
Fire spread to neighbouring buildings	OP3.1
Failure of sprinkler system to function as expected	OS1.4, OP1.4
Occupants not being able to recognize fire	OS1.4, OS1.5, OP1.4
Occupants not being able to evacuate the building	OS1.4, OS1.5, OP1.4
Fire Service unable to conduct effective firefighting operation	OS1.2, OS1.3, OP1.2, OP1.3, OP3.1

There may be other technical risks; however, those risks are not identified as they are not addressed by the current 2006 BCBC. As the method of analysing technical risk to draw comparison to a building currently permitted by the Code, it is not appropriate to identify risks outside the scope of the BCBC. Notwithstanding this, the risks being addressed by the Code objectives are in general agreement with the fire engineering principles recognized in Canada and internationally.

Based on the technical risks identified above, the following is an analysis of the risk with respect to the characteristics of the Proposed Code Change Building presented in Table 3. The reader is reminded that the following risk analysis is based on comparing a 5 or 6 storey wood-frame building to a 5 or 6 storey noncombustible building such as using light steel-frame permitted in Division B. It may be that certain aspects of the current Division B requirements may not address all current concerns, such as design of exit systems to account for aging population. However, such concern is globally applied to all buildings, combustible or noncombustible. Therefore, the authors have taken the approach to consider the existing Division B requirements as being the acceptable minimum level of performance in BC, irrespective of whether certain requirements may not address all current considerations. For discussion purposes, it may be useful to reference the schematics in *Appendix A*.

- **Risk of Ignition:** *Not likely to increase.*
  By limiting the building area to $1440m^2$ for 5 storeys and $1200m^2$ for 6 storeys, the Proposed Code Change Building will effectively have the same gross floor area of $7200m^2$ as currently permitted for the 4 storey combustible Group C building. As total floor area is not increased, the occupant loads are not increased. And given the occupancy is not changed, the risk of ignition due to human activity will not likely increase. Ignition of fire due to non-human activities in the building will not likely increase, as the building volume remains relatively the same.

- **Risk of Fire Spread beyond Point of Origin:** *Not likely to increase.*
  The current 2006 BCBC addresses fire spread by creating fire compartments, which include suites, public corridors and exits which are separated from each other by fire separations (walls and floors constructed to achieve the requite FRR as defined in the Code and determined by ULC-S101). As the gross floor area of the Proposed Code Change Building is not being increased from what is currently permitted, and that the requirement for interior fire separations will still apply, the risk of fire spread will not likely increase. With respect to fire spread in void spaces, this is adequately controlled by current fire blocking as is shown by the acceptability of unsprinklered 3 storey construction. For 5 or 6 storey combustible buildings, there may be an increased concern with fire spread in attics if sprinkler systems fail; however, this can be addressed by additional fire blocking. With respect to exterior fire spread through windows, combustible exterior cladding permitted for combustible buildings may lead to greater risk of fire spread; until this has been better-analysed, use of noncombustible cladding or

the limited types of combustible cladding permitted for noncombustible buildings would address this risk. Finally, although not specifically addressed by the Code objectives, comment of smoke spread is appropriate. For a 6 storey wood-frame building (not a high building), with proper fire separation and fire blockings, spread of smoke would be no different than a permitted 6 storey steel stud building.

- **Risk of Fire Spread to Neighbouring Buildings:** *Not likely to increase.*
  Exposure protection will not be affected by the Code change. However, as part of the project, it will be recommended that the 5 and 6 storey combustible buildings use noncombustible exterior cladding to address the risk of vertical fire spread. By limiting the risk of vertical fire spread on the exterior surface of the exterior wall, the risk of fire spread to neighbouring buildings due to radiation and convection heat transfer will not likely increase.

- **Risk of Failure of Sprinkler System to Control / Supress Fire:** *Likely to decrease.*
  The NFPA 13 standard will be the applicable sprinkler standard for 5 and 6 storey combustible buildings of residential occupancy. NFPA 13R is limited to buildings 4 storeys in building height. As sprinklers work on a per floor area basis and independent of whether the building is combustible or noncombustible, the risk of sprinkler failure leading to delays in fire alarm activation and control of fire spread and growth is likely decrease.

- **Risk of Occupants Not Able to Recognize Fire:** *Not likely to increase.*
  Occupant response to fire cues and decision-making prior to evacuation will not likely increase based on a mandatory central fire alarm system and sprinkler system for the building.

- **Risk of Occupants Not Being Able to Evacuate the Building:** *Not likely to increase.*
  As the total gross floor area is not being increased, the total occupant load will also not increase. Travel time to an exit is anticipated to decrease due to smaller building area (floor plate) as a result of permitting greater building height. Since the occupant load per floor will decrease, queuing at exits will be likely to decrease. Travel time within exit stairs will likely increase due to 2 additional storeys; however, as the exits will be separated by 1 hour fire rated construction, the increase in travel time within exits will be insignificant in terms of the overall evacuation process. Note that a 6 storey noncombustible 1 hour rated building is currently permitted by the Code and is permitted to have $6000m^2$ building area. Generally, greater floor area means longer travel distance and travel time. Greater area also means greater occupant load which would generally result in greater queuing at exit facilities. Therefore, by comparison, the approach for 6 storey wood-frame would seem conservative, specifically considering that both combustible and noncombustible buildings would require a 1 hour FRR and that the rating is not predicated on the type of construction material.

- **Risk of Fire Service Unable to Conduct Effective Operation:** *Not likely to increase.*
  In comparison to a sprinklered 4 storey residential building of combustible construction and a sprinklered 6 storey residential building of noncombustible construction, the Proposed Code Change Building is not likely to result in an increased technical risk with respect to the effectiveness of firefighting operation. Traditional unsprinklered 3 storey wood-frame construction relied on exterior firefighting operations. With the advent of buildings protected with monitored and supervised sprinkler systems the Code, and related firefighting practices have shifted to reliance on the sprinkler systems and interior firefighting access. This is reflected in Code changes eliminating the requirement for fire rated roofs in unsprinklered buildings; eliminating the requirement for access openings for firefighting in sprinklered buildings; removal of the requirement for larger buildings to face streets and introduction of 4

storey 1 hour construction; and the removal of 9m height limit. These changes all reflect that the Code does not anticipate exterior firefighting of sprinklered wood-frame buildings, in recognition of the reliability and effectiveness of automatic sprinkler system. Hence, the primary change from 4 to 6 storeys is Fire Department access up an additional 2 storeys of interior stairs. However, this is in part mitigated by the reduced floor area from maximum $1800m^2$ at 4 storeys to $1200m^2$ at 6 storeys, as well as the consideration that the operation would be no different than that of 6 storey steel-frame building with a 1 hour fire rated construction.

Firefighting as well as search and rescue operation would be no different from the current operation for a 6 storey noncombustible building or a 4 storey combustible building. By limiting the permitted building area for combustible building to 20% of that permitted for noncombustible building, which is what the Code currently employs, the technical risk with respect to use of combustible material is addressed. There is no foreseeable increase in risk with respect to the effectiveness of fire service operations, particularly considering that the Proposed Code Change building will be sprinklered (to NFPA 13). Four storey wood-frame buildings typically have unsprinklered attics. Extension to 6 storeys will require attics and balconies be sprinklered, as is already required by NFPA 13.

There is a risk of fire spread due to combustible exterior cladding for 5 and 6 storey buildings and balcony fires; however, this can be mitigated by imposing measures to limit flame spread on exterior cladding and use of automatic sprinklers in balconies.

As the building is over 3 storeys, standpipes will be inherently required by Code.

For rural areas where the Fire Department may have limited firefighting capabilities, the BCBC appendix commentary already notes that this can be addressed through either requiring mandatory sprinklers or imposing restrictions through municipal zoning bylaws. With respect to the sprinkler option, the Proposed Code Change building will be sprinklered. Where the local Fire Department lacks the capability of properly supporting the sprinkler system, additional measures such as emergency power generator, fire pump, and on-site water supply can be used to enhance the reliability of sprinkler system, in conjunction with enforcement of proper maintenance of sprinkler system.

Based on the above, a 5 or 6 storey wood-frame building of residential occupancy following the area ratio of 20% will not likely pose a greater technical risk than a 4 storey wood-frame building of residential occupancy currently permitted by the 2006 BCBC. In essence, the performance of a 6 storey combustible building and a noncombustible building both of residential occupancy will be the same when fire separations, structural fire-rating and exits are provided with the 1 hour FRR. This is because the fire-resistance rating, as a measure of endurance in a fire, is not predicated on the building material. However, to address the risk associated with use of combustible material, it is proposed to limit the allowable building area to $1440m^2$ for 5 storeys and $1200m^2$ for 6 storeys, consistent with the 20% ratio currently in place for the permitted building area between combustible and noncombustible residential buildings.

With respect to the abovementioned technical risks, other than the risk of ignition, it has been seen that with the use of automatic sprinklers, the risks have substantially decreased based on review of the fire statistics obtained from BSPB. Qualitatively, the statistics suggest that when a building is sprinklered, irrespective of the type of construction and the building height, the number of fire-related fatalities and injuries in buildings have significantly reduced and that there is no evidence to suggest a sprinklered 5 or 6 storey wood-frame building would expose the building and its occupants to a greater risk and that should there be an increase in risk, the statistics would suggest that such risk would be marginal in all of the areas identified by the BCBC, other than the risk of ignition.

PROCESS RISKS

Process risk is defined by BSPB as to mean: *processes that are not clearly defined, are poorly aligned with business objectives and strategies, do not satisfy stakeholders' needs, or expose assets to misappropriation or misuse. Process risk includes the following risk areas: industry readiness and competency in areas of both design and construction, readiness of warranty providers to provide insurance in accordance with Homeowner Protection Act, Fire Department capabilities, etc.*

In general terms, this can be paraphrased to mean practical concerns with constructing a 6 storey combustible building of residential occupancy – the risks associated with the unavoidable inability for the industry to deliver a building that is in full compliance with the BCBC. The process risks presented below are developed through consultation and interviews with two AHJs in BC, the Homeowner's Protection Office, 3 warranty providers, and researchers at Forintek.

At this stage, the following five general areas of process risk are identified:

- **Qualification of Design Professionals**
  A major concern raised by many interviewees is the need for qualified professionals. Currently, the Letters of Assurance do require a professional qualified in structural engineering, but do not specifically require a professional qualified in fire safety or building envelope design. Education in Building Code requirements is provided to Architects, but this is limited. Significant additional Building Code education is provided in the Certified Professional Course, but it is not specific to wood-frame construction, and the use of Certified Professionals is only optional and limited to Vancouver and Surrey. Nor is it clear that the Certified Professional Training addresses the intricacies of wood-frame construction.

  The increased complexity of 6 storeys, combined with the trend for unusual architectural elements, the impact of shrinkage on fire separations, fire blocking and fire stopping, the increased reliance on firewalls may necessitate the requirement for a professional engineer with expertise in fire engineering. It is noted that APEGBC has recently been given legislative approval to designate and regulate specializations and is developing Fire Protection Engineering as a recognized discipline. APEGBC has already developed a draft "Guidelines for Fire Protection Engineers" which is expected to be adopted by the Council in the near future. Therefore, there is a willingness to create a new Fire Protection Engineer designation and it is recommended that a Fire Protection Engineer be required as part of the design for 5 and 6 storey wood-frame buildings.

- **Qualification of Design Reviewer / AHJ**
  It is identified that with the proposed Code change to permit up to 6 storeys of wood-frame buildings of residential occupancy in the Building Code, significantly more complex buildings may be proposed as alternative solutions. This may include proposals for mixed occupancies, use of other types of combustible materials (given the Code is not specific on the type of construction), use of mixed combustible and noncombustible materials, creation of interconnected floor spaces and increase in building height. Development of these alternative solutions will require a thorough understanding of the fire science and fire engineering principles. As compliance with the objective-based Code can be achieved through either the acceptable solutions or the alternative solutions, it would be necessary that design reviewers or

AHJs have similar qualifications as that of design professionals. Although there is no regulatory framework currently in place, certain municipalities have addressed review of designs following either acceptable or alternative solutions through one of the following two means, both of which are considered appropriate:

- Peer-review through a 3rd party qualified professional.
- Employment of a qualified fire engineer competent in Building Code.

Both of these approaches are currently considered as appropriate solutions to address the process risk with respect to qualification of reviewers, though the peer-review approach is often considered as being more independent.

- **Readiness of Warranty Providers**
  Interviews with three major warranty providers in BC indicates that insurance for 5 or 6 storey wood-frame buildings of residential occupancy will be highly dependent on the competence and qualification of contractors. The warranty providers indicate that they would insure buildings initially based on contractors that have a demonstrated acceptable record with 4 storey wood-frame buildings.

- **Readiness and Qualification of Contractors / Trades**
  Construction of a 6 storey wood-frame building is not significantly different from 4 storey wood-frame; however, there is a significant concern anticipated with some contractors' ability to construct 4 storey wood-frame buildings and the same concern extends to 6 storey wood-frame buildings. The increase to 6 storeys increases the need to appropriately follow the correct design; therefore, the risk of unqualified contractors may increase. There is currently no process for qualification of contractors or the trades related to framing gypsum wallboard fire separation and fire blocking. Training for fire-stopping is available but is of little use without proper qualifications of those responsible for framing, fire blocking and fire separations.

- **Reliability of Membrane-based Fire Separation**
  Reliability of fire separation and fire protection of structural members is not an objective of the Building Code. However, the Code has traditionally addressed certain critical areas of reliability of construction indirectly through for example requiring 1.5 hour rated fire separation around parking garages and requiring concrete or masonry construction for firewalls and the horizontal fire separation of Division B, Article 3.2.1.2.

  The concern for wood-frame construction in general is the reliance on the fire separations as exposed wood would directly fuel a fire. Laboratory tests clearly show that a single layer of gypsum wallboard on wood joists can achieve a 1 hour FRR; however, there is little validation of actual constructed separations in the field. Recent NRC testing has shown that single layer designs are very susceptible to improper joint construction, improper attachment of the gypsum wallboard and improper installation. However, 2 layer designs have been shown to be significantly more robust. It is significant that tests in Japan, Europe and New Zealand, including the recent full scale 6 storey timber-frame project in the UK (T2000), have indicated the need for increasing durability of GWB-based fire protection.

  Further, with the increased use of engineered wood product such as OSB in the industry, there is a significant concern that pre-mature failure of the structural members due to fire may lead to progressive failure of the building. EWP-based loadbearing members are typically protected by Type X GWB which derives the fire-resistance rating from the moisture content of the wallboard. In some instances, an assembly with a single layer of Type X GWB protecting EWP joists can receive a 1 hour FRR from the CAN/ULC-S101 fire test after repeated testing or through different laboratories, as the fire test standard does not currently regulate repeatability of test result and furnace conditions. Although EWP presents an excellent solution in terms of structural and shrinkage aspects of building design, these products are significantly more susceptible to fail in a fire than the traditional sawn lumber due to the manufacturing process of EWP. EWPs use carbon-based polymers to hold wood together which can loosen structural integrity at low heat as the polymers decompose.

In view of these factors, it is considered that a one layer system may be inappropriate, specifically considering that gypsum wallboard may be subject to damage during the lifetime of a building and more often are incorrectly replaced. Based on these considerations, it is recommended that floor assemblies and wall assemblies of exits be required to use a 2 layer GWB design, unless the framing members are heavy-timber as defined in the Code. Although this concern applies equally to 4 or 6 storey buildings, it is appropriate to review it at this time for 5 and 6 storeys.

Further, with a STC requirement of 50 and guidelines recommending STC 55, the two layers of gypsum wallboard are usually required for sound purposes.

3.2 Structural

Technical Risks

Technical risk is as defined under Section 3.1 above. In application to 'Structural", this can be paraphrased to mean the level of risk associated with structural requirements that are built in compliance with Division B, Part 4 without significant defect.

The technical risks recognized by the 2006 BCBC are stated in Division A, Section 2.2. "Objectives". The Code objectives provide a clear outline of the structural requirements that the Code addresses. The objectives relating to Division B, Part 4 Structural Requirements area as follows:

- **OS2 Structural Safety**

  An objective of [the 2006 BCBC] is to limit the probability that, as a result of the design or construction of the building, a person in or adjacent to the building will be exposed to an unacceptable risk of injury due to structural failure. The risks of injury due to structural failure addressed in this Code are those caused by:

  OS2.1 – loads bearing on the building elements that exceed their loadbearing capacity
  OS2.2 – loads bearing on the building that exceed the loadbearing properties of the supporting medium
  OS2.3 – damage to or deterioration of building elements
  OS2.4 – vibration or deflection of building elements
  OS2.5 – instability of the building or part thereof

- **OH4 Vibration and Deflection Limitation**
  An objective of [the 2006 BCBC] is to limit the probability that, as a result of the design or construction of the building, a person in the building will be exposed to an unacceptable risk of illness due to high levels of vibration or deflection of building elements.

- **OP2 Structural Sufficiency of the Building**
  An objective of [the 2006 BCBC] is to limit the probability that, as a result of its design or construction, the building or part thereof will be exposed to an unacceptable risk of damage or loss of use due to structural failure or lack of structural serviceability. The risks of damage and of loss of use due to structural failure or lack of structural serviceability addressed in this Code are those caused by:

  OP2.1 – loads bearing on the building elements that exceed their loadbearing capacity
  OP2.2 – loads bearing on the building that exceed the loadbearing properties of the supporting medium
  OP2.3 – damage to or deterioration of building elements
  OP2.4 – vibration or deflection of building elements
  OP2.5 – instability of the building or part thereof
  OP2.6 – instability or movement of the supporting medium

- **OP4 Protection of Adjacent Building from Structural Damage**
  An objective of [the 2006 BCBC] is to limit the probability that, as a result of the design, construction or demolition of the building, adjacent buildings will be exposed to an unacceptable risk of structural damage. The risks of structural damage to adjacent buildings addressed in this Code are those caused by:

  OP4.1 – settlement of the medium supporting adjacent buildings
  OP4.2 – collapse of the building or portion thereof onto adjacent buildings
  OP4.3 – impact of the building on adjacent buildings

From the objectives, the following areas of technical risk can be established:

Table 5
Technical risks on structural addressed by the 2006 BCBC.

Technical Risk	Code Objective
Failure of building elements	OS2.1, OP2.1, OP4.2
Failure of the supporting medium (soil and rock)	OS2.2, OP2.2, OP4.1
Damage or deterioration of building elements	OS2.3, OP2.3, OP4.3
Issues related to vibrations and deflections	OS2.4, OP2.4, OH4, OP4.3
Instability of the building or part thereof	OS2.5, OP2.5
Instability or movement of the supporting medium	OP2.6

There may be other technical risks; however, those risks are not identified as they are not addressed by the current 2006 BCBC. As the method of analysing technical risk to draw comparison to a building currently permitted by the Code, it is not appropriate to identify risks outside the scope of the BCBC. Notwithstanding this, the risks being addressed by the Code objectives are in general agreement with the structural engineering principles recognized in Canada and Internationally.

The following is an analysis of the risk with respect to the Proposed Building Code Change presented in Table 5:

- **Risk of Failure of Building Element:**
  In general, the risk of failure of elements due to gravity loads is not likely to increase providing sound engineering judgement and generally established design methods are followed. CSA O86 provides a well established reliability based design for wood members which when closely adhered to should not increase the risk of failure. However, for lateral loads due to wind and seismic, the increase in height will have a substantial affect. Current provisions for lateral design in CSA O86 are generally not as advanced as for other materials such as concrete and steel. With regards to seismic, steel and concrete, Codes have for some time evolved the philosophies of capacity design which is just now being introduced into the Wood Code. As well, there are many assumptions required in determining lateral loads, distribution of forces, stiffness's of walls and diaphragms, and philosophies of design. Horizontal forces, deflections, vibrations, and inter-storey drifts will be significantly increased, and the current best practices should be scrutinized in order to ensure the level of risk is not increased. As part of our recommendations, we would propose that APEGBC and SEABC be consulted to provide a "best practices guide" which would establish guidelines to supplement the material Codes and provide design principles which are generally accepted by the engineering community. This guideline would be referenced from the Code, and would provide a minimum standard of practice for the design of 5 and 6 storey wood residential buildings. In addition to dealing with lateral design standards, it will likely need to cover standard practices as well for designing and detailing the gravity system, and establish minimum requirements for workmanship and tolerances which are currently not covered under CSA O86. As well, the guide should address how shrinkage is accommodated for in the design and detailing of the structural systems.

- **Risk of Failure of Supporting Medium:** *Not likely to increase.*
  Generally, the foundations would be of concrete and would be designed according to the Concrete Code. The foundation design would be coordinated with the requirements of the Building Code, and geotechnical investigation.

- **Risk of Damage or Deterioration of Building Elements:**
  As a result of the increased height of the building, the cumulative effects of workmanship, tolerances, shrinkage, and increased lateral loads may increase the risk of damage to building elements unless careful attention is played to the design, detailing, and coordination amongst the design professionals and trades. In order to mitigate any risk, our recommendation would be that workmanship, tolerances and issues related to shrinkage should be addressed by the "best practices guide" as proposed above. It would also be proposed that potential lateral and vertical movements of each floor would need to be provided and addressed by the design and construction trades such that the risk of damage to building elements would not likely increase.

- **Risk of Issues Related to Vibrations and Deflections:**
  See "Risk of Failure of Building Elements" and "Risk of Damage or Deterioration of Building Elements" above.

- **Risk of Instability of the Building or Part Thereof:**
  See "Risk of Failure of Building Elements" and "Risk of Damage or Deterioration of Building Elements" above.

- **Risk of Instability or Movement of the Supporting Medium:** *Not likely to increase.*
  See section above for "Risk of Failure of Supporting Medium".

Process Risks

Process risk is defined as per Section 3.1 above. In general terms, this can be paraphrased to mean practical concerns with constructing a 6 storey combustible building of residential occupancy – the risks associated with the unavoidable inability for the industry to deliver a building that is in full compliance with the BCBC. The process risks presented below are based on consultation with local engineers, past experiences, and a review of various papers.

The following general areas of process risk are identified.

- **Qualification of Design Professionals**
  A major concern raised by many local practitioners is that there is not a well established "best practices guideline" for the design and detailing of wood-frame projects. Many practitioners agree that the level of competency, knowledge, and standard of drawings varies substantially within the wood industry. It has been suggested by some of the design community that it would be prudent to require that the responsibility for the design and detailing for 5 and 6 storey wood projects be undertaken by a qualified Designated Structural Engineer (Struct. Eng.) as defined by APEGBC. This may be added as part of the BC Building Code requirements under Division C Part 2 "Administrative Provisions".

- **Independent Concept Review and Independent Construction Review**
  It is also in general agreement, that a registered Struct. Eng. be required to provide an independent peer review of the design documents. The proposed "Best Practices Guide" would be used as a terms of reference. This may include the requirement for a further schedule endorsed by APEGBC to be signed and sealed by the independent reviewer. Furthermore, for critical elements, it is also suggested that independent construction reviews be required by the peer reviewer. The scope for this would need to be established. This requirement may also be referenced as part of the BC Building Code requirements under Division C, Part 2 "Administrative Provisions".

- **Preparation of a "Best Practices Guide"**
  It was generally suggested by a group of local practitioners that a "Best Practises Guide" be prepared to provide guidance where Codes and handbooks are vague. It is also suggested that this may be referenced from the BC Building Code, or its appendix. The content of the guide would need to be agreed upon by the design community but may include items such as:

  - Minimum drawing and detailing requirements
  - A guide for the design and detailing of wood lateral systems for wind and seismic.
  - Provisions for Hybrid Structures, including the integration of other materials and systems into a wood building,
  - Methods to determine, detail for, and document estimated building movements – such as vertical due to shrinkage of wood and lateral movements due to wind and seismic.
  - Minimum workmanship requirements and tolerances.
  - Establishing suitable load paths for forces and systems for both vertical and lateral loads.

- Provisions for the stability of vertical members where drywall is considered to stabilize compression members. Drywall Sheathing may not be suitable as a bracing material for the higher loads, or where it is damaged by water, or lateral loads.
- Recommendations for the design of platform structures (i.e. Wood-frame on top of a concrete building) and transfer of loads to supporting platform.

- **An Increased Awareness for all Design Professionals, Contractors and Trades**
  It is suggested, that a series of training seminars be provided to all the design professionals, contractors and trades to increase the awareness of challenges related to increasing the current allowable height limit.

- **Monitoring and Reporting for New 5 and 6 Storey Buildings**
  As part of the initial infancy of a new Code provisions, it is recommended that a government / engineering community develop and endorse a monitoring and reporting program to provide feedback to the design community on the performance of taller wood structures.

- **Further Testing and Codification of Wood Lateral Resisting Systems**
  The current Canadian Codes and design standards with regards to designing and detailing for lateral loads in wood-frame buildings has only rapidly evolved only over the past 20 years. However, the wood industry still lags other materials with regards to capacity design principals which have been well established for other materials based on testing. A further understanding of shear yielding elements should also be developed similarly to that which has been developed for metal deck diaphragms. Although a best practices guide is recommended to be developed, it is suggested that further testing will be required to assist in developing the design and detailing requirements for wood based lateral resisting systems utilized in seismic zones.

- **Licensing of Contractors and Trades**
  It is suggested that the necessity to require licensing for trades and contractors involved in 5 to 6 storey building discussed within the design and construction community.

3.3 Building Envelope

Technical Risks

Technical risk is defined in Section 3.1 above. In application to 'Building Envelope', this can be paraphrased to mean the level of risk associated with 'environmental separators' that are built in full compliance with Division B, Part 5 without significant defect.

A quantitative analysis of the technical risk with respect to 'structural shrinkage, sound transmission, building techniques, moisture, material shrinkage, etc.' impacts on environmental separators, would be impossible as 6 storey light wood-frame buildings do not currently exist in BC. Because of our unique climate, it would also be difficult to draw a reasonable comparison to the building envelope risks on any 6 storey light wood-frame buildings built in other jurisdictions. Therefore, it is necessary to employ a qualitative approach by comparing the risk between 4 and 6 storey residential buildings and 6 storey noncombustible buildings.

The technical risks recognized by the 2006 BCBC are stated in Division A, Section 2.2 "Objectives". The Code objectives provide a clear outline of the environmental separation issues that the Code addresses. The objectives relating to Division B, Part 5 - Environmental Separators are as follows:

- **OS1 Fire Safety**
  An objective of [the 2006 BCBC] is to limit the probability that, as a result of the design or construction of the building, a person in or adjacent to the building will be exposed to an unacceptable risk of injury due to fire. The risks of injury due to fire addressed in this Code are those caused by:

  OS1.4 – fire safety systems failing to function as expected [Applies where required life safety systems are incorporated in environmental separators]

- **OS2 Structural Safety**
  An objective of [the 2006 BCBC] is to limit the probability that, as a result of the design or construction of the building, a person in or adjacent to the building will be exposed to an unacceptable risk of injury due to structural failure. The risks of injury due to structural failure addressed in this Code are those caused by:

  OS2.1 – loads bearing on the building elements that exceed their loadbearing capacity
  OS2.2 – loads bearing on the building that exceed the loadbearing properties of the supporting medium
  OS2.3 – damage to or deterioration of building elements
  OS2.4 – vibration or deflection of building elements
  OS2.5 – instability of the building or part thereof

- **OS3 Safety in Use**
  An objective of [the 2006 BCBC] is to limit the probability that, as a result of the design or construction of the building, a person in or adjacent to the building will be exposed to an unacceptable risk of injury due to hazards. The risks of injury due to hazards addressed in this Code are those caused by:

  OS3.1 – tripping, slipping, falling, contact, drowning or collision

- **OH1 Indoor Conditions**
  An objective of [the 2006 BCBC] is to limit the probability that, as a result of the design or construction of the building, a person in the building will be exposed to an unacceptable risk of illness due to indoor conditions. The risks of illness due to indoor conditions addressed in this Code are those caused by:

  OH1.1 – inadequate indoor air quality
  OH1.2 – inadequate thermal comfort
  OH1.3 – contact with moisture

- **OH3 Noise Protection**
  An objective of [the 2006 BCBC] is to limit the probability that, as a result of the design or construction of the building, a person in the building will be exposed to an unacceptable risk of illness due to high levels of sound originating in adjacent spaces in the building (See Sentence 2.1.1.2.(3) for application limitation). The risks of illness due to high levels of sound addressed in this Code are those caused by:

  OH3.1 – exposure to airborne sound transmitted through assemblies separating dwelling units from adjacent spaces in the building

- **OH4 Vibration and Deflection Limitation**
  An objective of [the 2006 BCBC] is to limit the probability that, as a result of the design or construction of the building, a person in the building will be exposed to an unacceptable risk of illness due to high levels of vibration or deflection of building elements

- **OP2 Structural Sufficiency of the Building**
  An objective of [the 2006 BCBC] is to limit the probability that, as a result of its design or construction, the building or part thereof will be exposed to an unacceptable risk of damage or loss of use due to structural failure or lack of structural serviceability. The risks of damage and of loss of use due to structural failure or lack of structural serviceability addressed in this Code are those caused by:

  OP2.6 – instability or movement of the supporting medium

From the objectives, the following areas of technical risk can be established:

Table 6
Technical risks on building envelope addressed by the 2006 BCBC

Technical Risk	Code Objective
Risk of failure of fire safety systems (in environmental separators)	OS1.4
Structural safety risks due to failure of environmental separators	OS2.1, OS2.2, OS2.3, OS2.4, OS2.5
Failure of environmental separators, leading to safety risks	OS3.1
Risk of illness due to indoor conditions	OH1.1, OH1.2, OH1.3
Risk of illness due to high levels of sound	OH3.1
Risk of illness due to high levels of vibration or deflection of building elements	OH4
Risk of damage and of loss of use due to structural failure or lack of structural serviceability	OP2.6

There may be other technical risks; however, those risks are not identified as they are not addressed by the current 2006 BCBC. As the method of analysing technical risk to draw comparison to a building currently permitted by the Code, it is not appropriate to identify risks outside the scope of the BCBC. Notwithstanding this, the risks being addressed by the Code objectives are in general agreement with the building science principles recognized in Canada and internationally.

Based on the technical risk identified above, the following is an analysis of the risk with respect to the Proposed Code Change Building presented in Table 6:

- **Risk of Failure of Fire Safety Systems in Environmental Separators:** *Not likely to increase.*
  Current 2006 BCBC Part 5 provisions require the design of environmental separators to include building materials, components and assemblies to accommodate all loads, and resist any deterioration, that may be reasonably expected, given the exposure. While the exposure, and hence associated loads and deterioration risks, will be increased in taller wood-frame buildings; Part 5 requires that the materials, components and assemblies be designed to accommodate these expected risks.

- **Structural Safety Risks due to Failure of Environmental Separators:** *Not likely to increase.*
  Current 2006 BCBC Part 5 provisions require the design of environmental separators to include building materials, components and assemblies to accommodate all loads, and resist any deterioration, that may be reasonably expected, given the exposure. While the exposure, and hence associated loads and deterioration risks, will be increased in taller wood-frame buildings; Part 5 requires that the materials, components and assemblies be designed to accommodate these expected risks.

- **Risk of Failure of Environmental Separators, Leading to Safety Risks:** *Not likely to increase.*
  Current 2006 BCBC Part 5 provisions require the design of environmental separators to include building materials, components and assemblies to accommodate all loads, and resist any deterioration, that may be reasonably expected, given the exposure. While the exposure, and hence associated loads and deterioration risks, will be increased in taller wood-frame buildings; Part 5 requires that the materials, components and assemblies be designed to accommodate these expected risks.

- **Risk of Illness due to Indoor Conditions:** *Not likely to increase.*
  Current 2006 BCBC Part 5 provisions require the design of environmental separators that separate; interior conditioned space from exterior space, interior space from the ground, or environmentally dissimilar spaces; such that they provide acceptable conditions for the building occupants, maintain appropriate conditions for the intended use, and minimize accumulation of condensation in, and the penetration of precipitation into, the building components or assemblies; such that the health or safety of building users will not be adversely affected. While the exposure, and hence associated loads and deterioration risks, will be increased in taller wood-frame buildings; Part 5 requires that the materials, components and assemblies be designed to accommodate these expected risks.

- **Risk of Illness due to High Levels of Sound:** *Not likely to increase.*
  Current 2006 BCBC Part 5 provisions require the design of environmental separators such that dwelling units are separated from; every other space in the building in which noise may be generated by construction with an STC rating not less than 50, and from elevator hoistways or refuse chutes by construction with an STC rating not less than 55. These risks are independent of building height, and are not likely to be affected by constructing taller wood-frame buildings.

- **Risk of Illness due to High Levels of Vibration or Deflection of Building Elements:** *Not likely to increase.*
  Current 2006 BCBC Part 5 provisions require the design of environmental separators to include building materials, components and assemblies to accommodate all loads that may be reasonably expected, given the exposure, and to provide stipulated STC ratings for specific environmental separators. While the exposure, and hence associated loads, will be increased in taller wood-frame buildings; Part 5 requires that the materials, components and assemblies be designed to accommodate these expected risks. The issues associated with provision of the stipulated STC ratings are not related to building height.

- **Risk of Damage and of Loss of Use due to Structural Failure or Lack of Structural Serviceability:** *Not likely to increase.*
  Current 2006 BCBC Part 5 provisions require the design of environmental separators to include building materials, components and assemblies to accommodate all loads, and resist any deterioration, that may be reasonably expected, given the exposure. While the exposure, and hence associated loads and deterioration risks, will be increased in taller wood-frame buildings;

Part 5 requires that the materials, components and assemblies be designed to accommodate these expected risks.

Based on the above, it is shown that within the framework of Part 5 of the 2006 BCBC, a 5 or 6 storey combustible building of residential occupancy following will not likely pose a greater technical risk than a 4 storey wood-frame building of residential occupancy currently permitted. The performance of a 4 storey or 6 storey wood-frame building, both of residential occupancy, will be the same when the environmental separators are designed to accommodate the expected exposure, and hence associated loads and deterioration risks. The building materials, components and assemblies will necessarily be different than they would be in an equivalent 4 storey building, but Part 5 makes it clear that it is incumbent on the designer to reflect on the increased risks, and design accordingly.

PROCESS RISKS

Process risk is defined in Section 3.1 above. In general terms, this can be paraphrased to mean practical concerns with constructing a 6 storey wood-frame building of residential occupancy – the risks associated with the unavoidable inability for the industry to deliver a building that is in full compliance with the BCBC. The process risks presented below were developed through consultation and interviews with other Building Envelope Professionals, the Homeowner's Protection Office, and 3 warranty providers. At this stage, two general areas of process risk associated with building envelope concerns have been identified; qualifications of project team members and lack of supporting technical information sources, such as best practice guides.

- **Qualification of Design Professionals**
  A major concern raised by interviewees was the need for qualified professionals. Currently, the Letters of Assurance require an Architect to sign off on building envelope issues, but only in the City of Vancouver is there a specific requirement for a professional qualified in building envelope design and review, to sign a separate schedule letter. A Building Envelope Education Program (BEEP) has been provided by the AIBC, but this was limited to an understanding that people attaining the Building Envelope Professional (BEP) designation (that the courses were designed to meet) would be qualified to practice in the design and review of conventional wood-frame construction (to a maximum of 4 storeys). Other building envelope education courses for professionals have been provided by APEGBC, UBC, and BCIT (amongst others), but obviously none of these have been specifically tailored to include sections on reducing building envelope risks associated with the complexities of taller wood-frame construction. If we are to develop professionals capable of dealing with the risks associated with issues such as higher building exposure, and increased shrinkage problems, course contents, and subsequent qualifications for professionals will have to be re-visited. With the recent passage of Bill 10, the AIBC and APEGBC are starting to work toward re-instating a 'BEP' qualification. Within this work, an assessment of the skills and qualifications necessary to design and field review the building envelopes of 6 storey wood-frame buildings will become another task they will need to address.

- **Readiness of Warranty Providers / Qualification of Contractors**
  As HPO mandated warranties, created to deal with building envelope failure, rely heavily on the knowledge and skill sets of the Contractors doing the building (along with the professionals on the project team), the three warranty providers interviewed indicated that insurance for 5 or 6 storey wood-frame buildings of residential occupancy will be dependent on qualifying contractors who they believe will be able to mitigate the associated risks. There would be concern with their ability to construct a durable building envelope to deal with the higher

exposure created by a 6 storey wood-frame construction. The warranty providers indicated that they would initially only want to insure buildings built by contractors that have a solid record of building 4 storey wood-frame buildings.

- **Readiness of Trades**
  Another major link in the project team identified by interviewees, as needing upgraded skills, are the trades who the contractors will employ to build 5 or 6 storey wood-frame buildings. Trades training programs for Building Envelope Technicians are still in early development, and will need to be revised to provide the skills necessary to address this new building type.

- **Best Practice Guides**
  Technical literature for the industry will need to be updated and expanded to provide the technical resources to focus on the building envelope risks in taller wood-frame buildings. The CMHC worked with the local industry to develop Best Practice Guides, such as "Wood-frame Envelopes in the Coastal Climate of British Columbia". This document (along with others) will need to be updated to address a taller wood-frame building type. The technical recommendations outlined in guides addressing varying exposures, and shrinkage problems will need to be re-thought to provide the necessary technical information for the industry, in order to lower the risks associated with going taller in wood-frame construction.

CONCLUSION

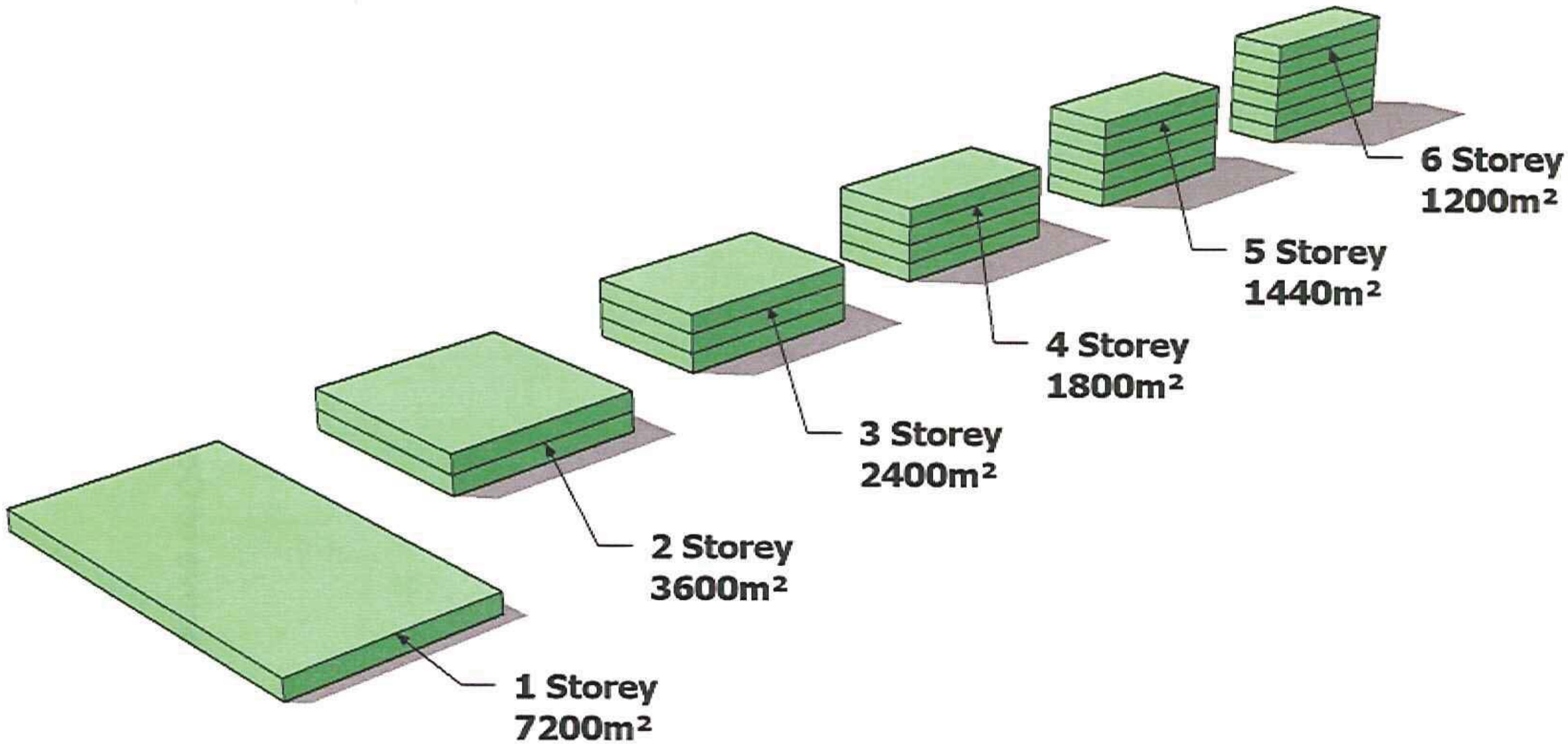
This Stage 1 Report has summarized the existing Code provisions for residential buildings with respect to fire safety, structural and building envelope aspects of the proposed Code change. The report has provided a review of the role of the Building Code and its purpose and objectives in relation to risks in building construction in BC. This report has only specifically identified technical and process risks as requested by BSPB and the identification is based on GHL and RJC's professional experience and limited review of literature and consultation as permitted within the 3 week timeframe of this project.

The report has identified that in general, the technical risks will not likely increase. With respect to Division B requirements, wood-frame buildings are only permitted to be 4 storeys due to Part 3 limitations. In general, it is considered that no significant increase in technical risks would result if the existing philosophy of 1 hour FRR and the 20% ratio between permitted building areas of combustible and non-combustible construction is retained. There are, however, a number of process risks for fire, structural and building envelope design considerations that have been identified, which are not necessarily contingent on the Code change, but rather require other regulatory means of addressing the issues.

Based on our review to date, we do not foresee any significant issues that would discourage us from proceeding with Stage 2 of this project.

APPENDIX A

Schematic Perspective of Combustible and Noncombustible Residential Buildings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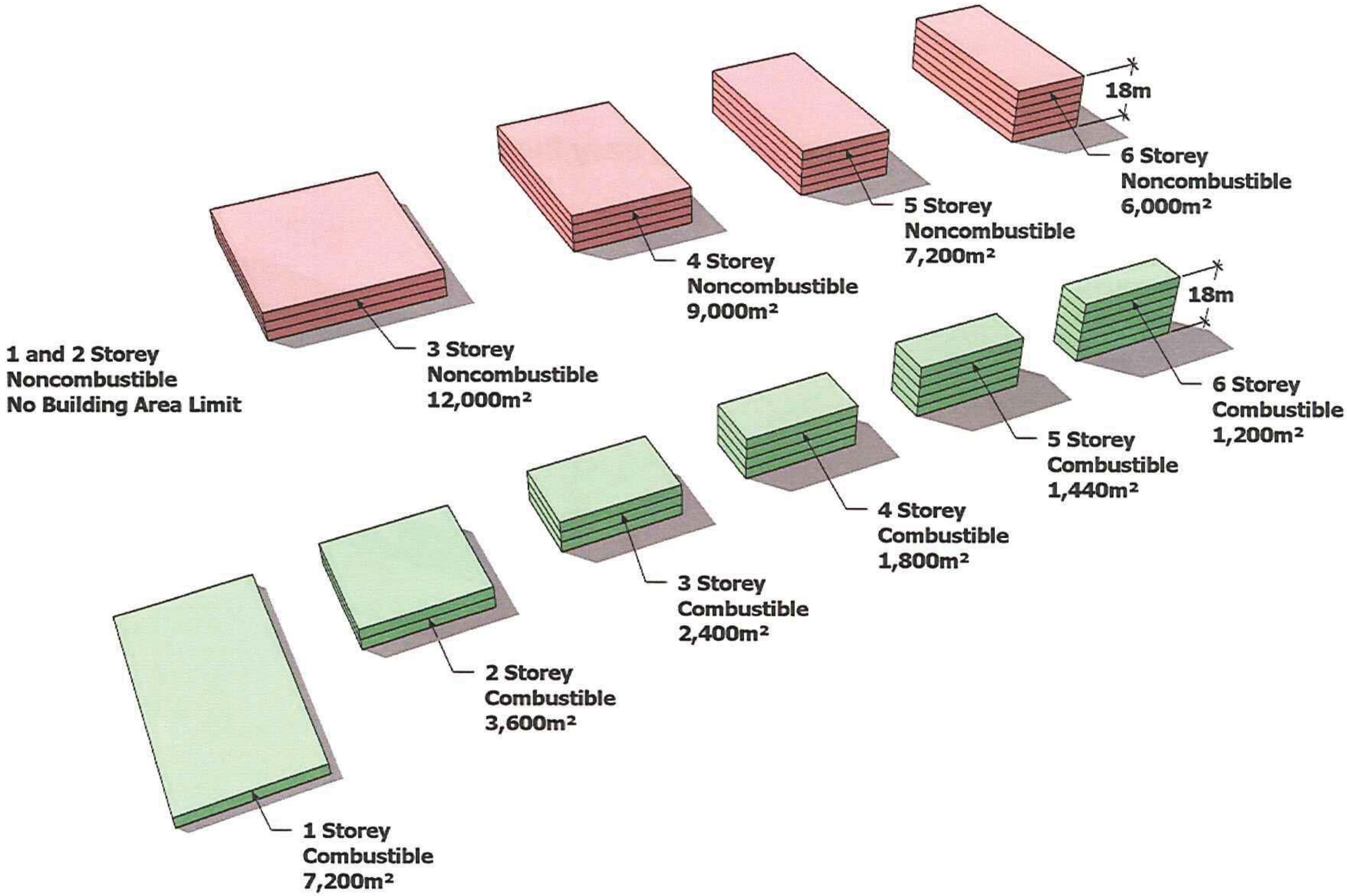
2 Storey
3600m²
3 Storey
2400m²
4 Storey
1800m²
5 Storey
1440m²
6 Storey
1200m²


18m
6 Storey
Noncombustible
6,000m²
5 Storey
Noncombustible
7,200m²
4 Storey
Noncombustible
9,000m²
3 Storey
Noncombustible
12,000m²
1 and 2 Storey
Noncombustible
No Building Area Limit
18m
6 Storey
Combustible
1,200m²
5 Storey
Combustible
1,440m²
4 Storey
Combustible
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Combustible
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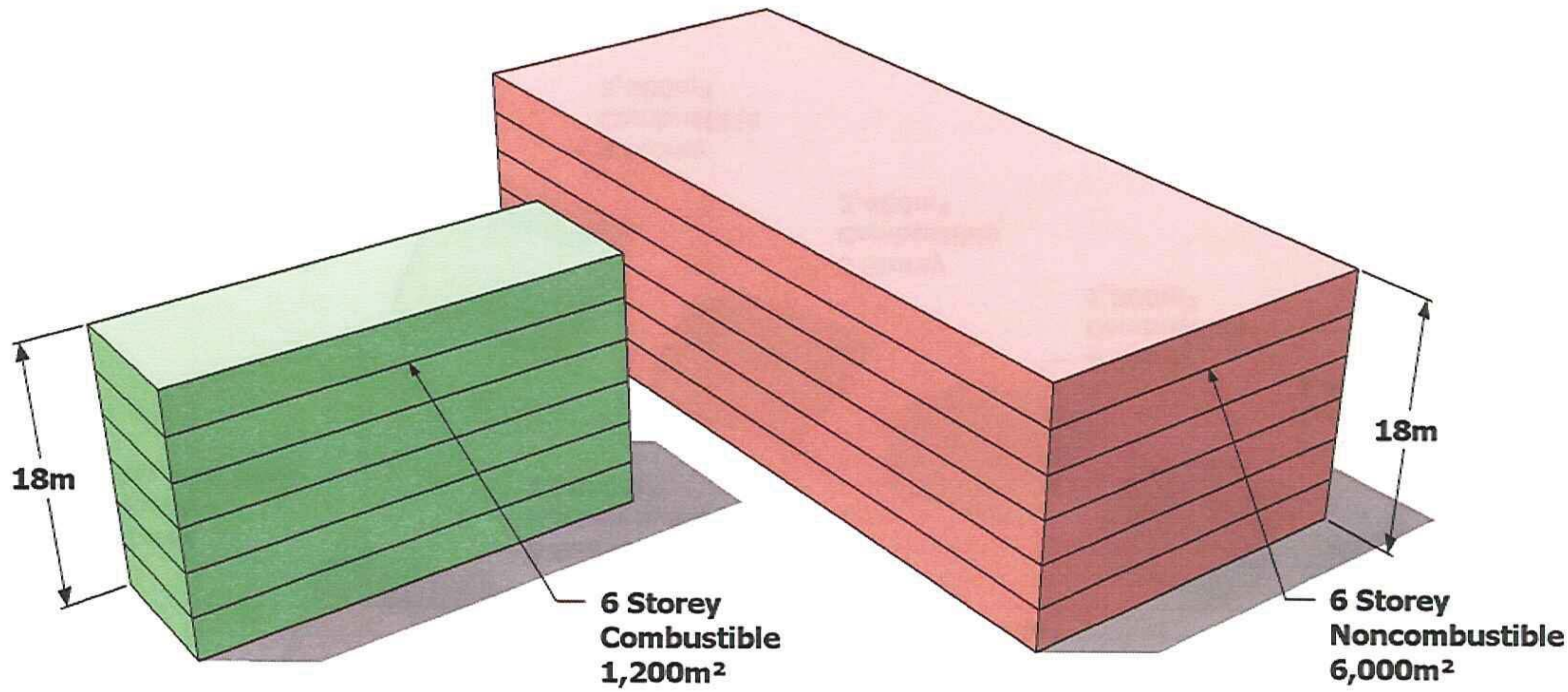
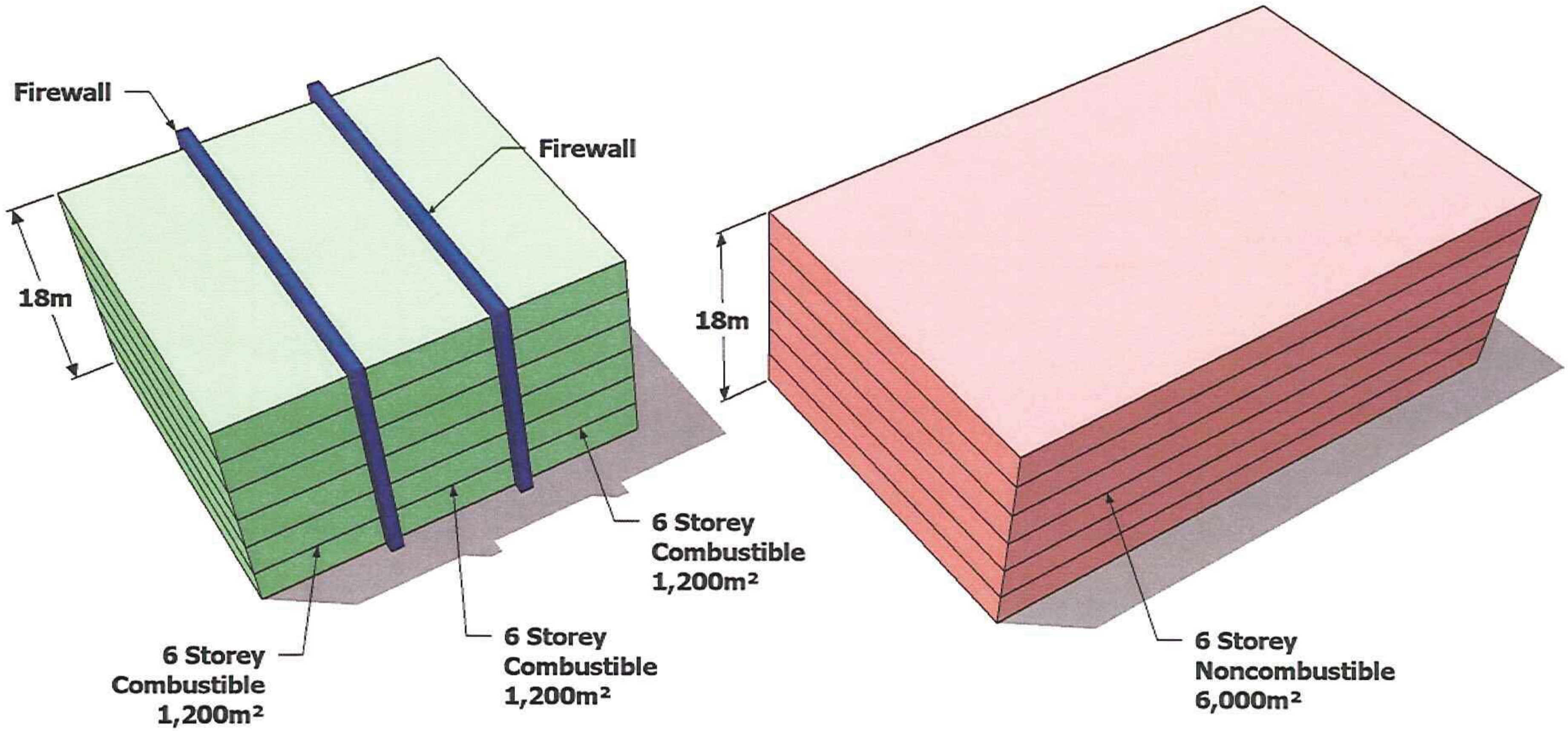
Combustible
3,600m²
1 Storey
Combustible
7,200m²



Building Area Comparison



Building Area Comparison

(Example of Combustible Buildings separated by Firewalls)

GHL CONSULTANTS LTD

Read Jones Christoffersen Consulting Engineers

Building and Safety Policy Branch
Ministry of housing and Social Development
Amending the BC Building Code to Permit up to and including 6 Storeys of Wood-Frame Buildings of Residential Occupancy

Stage 2 Report

Recommended Building Code Changes to permit 5 and 6 Storey Wood-Frame Buildings of Residential Occupancy

October 28, 2008

Prepared by

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GHL File No.: BSP-3517.00

RJC No.: 100419.P000
100419.P001

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SUMMARY

Stage 2 Report – Recommended Building Code Changes to permit 5 and 6 Storey Wood-Frame Buildings of Residential Occupancy

As part of the recent initiative to amend the current BC Building Code (BCBC) to permit up to and including 6 storeys of wood-frame construction of residential occupancy, GHL Consultants Ltd (GHL) and Read Jones Christoffersen Ltd (RJC) have been requested by the Building and Safety Policy Branch of the Ministry of Housing and Social Development to prepare the following Stage 2 Report which provides the recommended Code changes to permit 5 and 6 storey wood-frame buildings in BC, as well as the associated technical and process risks identified in the Stage 1 Report.

The Stage 2 Report includes recommended Code changes and rationales to Division B, Parts 3 and 4 and the associated appendix notes. No Code change is recommended for Division B, Part 5 as it is a performance-based Code.

The Stage 2 Report must be read in conjunction with the Stage 1 Report for completeness.

TABLE OF CONTENT

LIST OF ILLUSTRATIONS

ABBREVIATIONS

AHJ	Authority Having Jurisdiction
AIBC	Architectural Institute of British Columbia
APEGBC	Association of Professional Engineers and Geoscientists of British Columbia
BC	British Columbia
BCBC	British Columbia Building Code
BCIT	British Columbia Institute of Technology
BEEP	Building Envelope Education Program
BEP	Building Envelope Professional
BSPB	Building and Safety Policy Branch
CANCEE	Canadian National Committee on Earthquake Engineering
CMHC	Canada Mortgage and Housing Corporation
CP	Certified Professional
CAN/ULC-S101	Fire Test Standard “Fire Endurance Tests of Building Construction and Materials”
CSA	Canadian Standards Association
CSA O86	CSA Standard “Engineering Design in Wood”
EWP	Engineered Wood Product
FRR	Fire-resistance rating
GHL	GHL Consultants Ltd
Group C	Residential occupancy as defined in the 2006 BCBC
GWB	Gypsum wallboard
HPO	Homeowner Protection Office
IRC	Institute for Research in Construction
NBCC	National Building Code of Canada

NFPA	**National Fire Protection Association**
NFPA 13	**NFPA Standard “Installation of Sprinkler Systems”**
NRC	**National Research Council**
OSB	**Oriented Strandboard**
RJC	**Read Jones Christoffersen Ltd**
SEABC	**Structural Engineers Association of British Columbia**
STC	**Sound Transmission Class**
Struct.Eng	**Designated Structural Engineer**
UBC	**University of British Columbia**
ULC	**Underwriter’s Laboratory of Canada**
ULC-S101	**Fire Test Standard “Fire Endurance Tests of Building Construction and Materials”**

DISCLAIMER

This technical report is prepared by GHL and RJC for the Ministry of Housing and Social Development. The purpose of this report is to provide a professional opinion to the Ministry on the recommended Code changes to permit up to and including 6 storeys wood-frame buildings of residential occupancy. The recommended Code changes are based on GHL and RJC's work as documented in the Stage 1 Report. The work of this Stage 2 report, as well as the Stage 1 Report, is limited by the timeframe, which would normally require substantial research for a significantly greater duration. The sole objective of this report is to provide a set of recommended Code changes aimed at permitting 5 and 6 storey wood-frame buildings and addressing the related technical and process risks in fire safety, structural and building envelope designs, as have been identified in the Stage 1 Report. The work as presented in this report is based on GHL and RJC's knowledge as competent practitioners in their respective fields. GHL and RJC's work shall not be construed as exhaustive. There may be other relevant considerations for the Code change proposal not identified by GHL and RJC. It is understood that a public consultation process is being carried-out in conjunction with this report. The decision to accept the risk of any type of construction or related issue identified is a decision by the BC Government to accept the associated level of risk. Enacting, changing or amending the Building Code for BC is the authority of the BC Government by laws of British Columbia and Canada. GHL and RJC are not responsible for the decision to accept the risks. The BC Government shall be solely responsible for the act of amending the BC Building Code to permit up to and including 6 storeys of wood-frame construction of residential occupancy, or making any changes to any provisions in the Building Code. It is the BC Government's sole discretion to adopt, consider or accept any part or in full the work of GHL and RJC contained in this report. GHL and RJC shall not be responsible for any loss of any kind that may arise due to any construction, building, or structure as a result of GHL and RJC's work or any Building Code or construction regulation change in British Columbia, or anywhere. Should this report be made available to other organizations that have regulatory capacity in construction of buildings and structures for anywhere this disclaimer shall equally apply. By preparing this report GHL and RJC do not express explicitly or implicitly any social, economical or political opinion, or any other non-technical opinion, as it relates to the Code change proposal. This report is intended to be purely technical in nature. Any inquiries on this report shall be directed to the Ministry:

Manager
Building and Safety Policy Branch
Office of Housing and Constructions Standards
Ministry of Housing and Social Development
5th Floor, 609 Broughton street
PO Box 9844 Stn Prov Govt
Victoria, BC V8W 9T2
Email building.safety@gov.bc.ca

1.0 BASIS OF REPORT

1.1 Stage 2 Report

As part of the recent initiative to amend the current BC Building Code (BCBC) to permit up to and including 6 storey combustible buildings of residential occupancy, GHL Consultants Ltd (GHL) and Read Jones Christoffersen Ltd (RJC) have been requested by the Building Safety and Policy Branch (BSPB) of the Ministry of Housing and Social Development to prepare the following Stage 2 Report which provides the recommended Code changes to address the technical and process risks identified in the Stage 1 Report. The Stage 2 Report includes the recommended text for the Code changes and their rationales, specifically developed to address 5 and 6 storey wood-frame building of residential occupancy. Although the recommendations are for 5 and 6 storey wood-frame buildings of residential occupancy, some of these recommendations are applicable to other buildings. Where appropriate, the report identifies the recommendations that should also be extended to include non-5 and 6 storey wood-frame buildings of residential occupancy. This Stage 2 Report shall be read in conjunction with the Stage 1 Report for completeness.

1.2 Role of GHL and RJC

The role of GHL and RJC as consultants to BSPB is to recommend, to the best of our professional knowledge, Code changes to address technical and process risks in fire safety, structural and building envelope as determined by our work in Stage 1 with respect to 5 and 6 storey wood-frame buildings. GHL and RJC are retained to address conventional wood-frame construction typical in BC; we have not been retained to address any other types of combustible construction. However, for consistency with the Code, we have used the term "combustible construction" in this report; see Section 1.5 for further discussion.

1.3 Role of the BC Building Code

The BCBC is the Building Code for British Columbia, except Vancouver where it is governed by the Vancouver Building Bylaw. The BCBC is the regulation that governs building construction in BC. The 2006 BCBC is the edition of the BCBC currently in effect, and it is an objective-based Building Code. Code compliance with the 2006 BCBC is achieved by demonstrating compliance with the Code objectives. It is noted that the design of a technically sound building depends upon many factors beyond simple compliance with the Building Code. The 2006 BCBC has the following 5 broad objectives, which are further refined into specific objectives that translate into Code requirements **[1]**:

- Safety
- Health
- Accessibility for persons with disabilities
- Fire protection of building and facilities
- Energy

As an objective-based Code, the 2006 BCBC provides 2 avenues for Code compliance. One is prescriptive through meeting the acceptable solutions in Division B. The other is by alternative solutions, which often requires technical substantiation to demonstrate that a proposed design will achieve a level of performance that meets the minimum required by the Building Code. Division A Appendix A-1.2.1.1.(1)(a) and (b) further clarifies Code compliance via acceptable solutions and via alternative solutions.

As an objective-based Code, the BCBC does not restrict the design and construction of a building to the acceptable solutions. The Code provides an opportunity to achieve Code-compliance through alternative solutions should it be desired. It is known that 5 and 6 storeys wood-frame buildings have been built previously under equivalencies and alternative solutions, often as a “podium” structure where the first storey is noncombustible of commercial use and the remaining being residential wood-frame.

However, in the absence of an acceptable solution in Division B to specifically recognize 5 and 6 storey combustible buildings, designers and AHJs alike are not given a clear basis for the design and review of such buildings. This is because the majority of the Code requirements are largely predicated upon the construction Article determined in Subsection 3.2.2., which is determined based on building characteristics including sprinkler provision, building height, building area, and occupancy classification. Therefore, without an acceptable solution to recognize the constitution of 6 storey combustible buildings, it is difficult for designers and AHJs to justify such building, as well as any related alternative solutions, because it is difficult if not impossible to provide an analysis for a design not specifically defined in Division B.

1.4 Public Interest Decision

Changing the Building Code is a public-interest decision. The BCBC has been changed and revised since its first enactment in 1973. The act of enacting and revising the Building Code is defining the acceptable minimum level of performance for buildings in British Columbia. Risk is generally defined as the product of probability of failure and the consequence. Division B of the Building Code defines the boundaries between acceptable risk and the “unacceptable” risks referred to in the statements of the Code objectives. That is, any risk remaining once the applicable acceptable solutions in Division B have been implemented represents the residual level of risk deemed to be accepted by the broad base of British Columbians who have taken part in the consensus and legislative processes used to develop the BCBC **[1]**. Therefore, by changing the Building Code to permit up to and including 6 storeys of combustible building of residential occupancy, it is an act to acknowledge and accept all risks associated with the Code change.

1.5 Assumptions

Combustible Construction

The work presented in this report assumes traditional wood-framing construction employed in BC as requested by the Ministry. This assumption is consistently used in with respect to structural and building envelope discussion in this report as the respective Part of the Code are more specific on the type of material and construction technique. However, with respect to Division B Part 3, the term “combustible construction” is used as in terms of fire safety, the Code requirements of this Part are founded on the basis of combustible versus noncombustible construction materials, notwithstanding that the typical combustible construction in BC is wood-frame construction as limited by other Codes, standards and engineering requirements outside of Division B, Part 3. The terminology on “combustible construction” and “wood-frame” construction can generally be considered as interchangeable, except with respect to fire safety, it should be noted that combustible construction could potentially include other types of combustible material through alternative solutions, and that GHL and RJC have only been retained to address wood-frame construction.

Scope of Code Change

The work also assumes changing the Building Code with respect to fire safety, structural and building envelope requirements in Division B, Part 3, Part 4 and Part 5, respectively. GHL and RJC have not been requested to provide work relating to any other aspect of the Building Code outside of Division B, Part 3, Part 4 and Part 5, including construction fire safety. Specifically, GHL has only been requested to comment on fire safety requirements pertaining to Part 3; other requirements such as occupant safety due to building usage and accessibility as well as health requirements contained in Part 3 are not part of the scope of GHL's work. At time of report writing GHL and RJC have recommended BSPB to retain qualified professionals to address other requirements such as including but not limited to construction fire safety, as well as electrical and mechanical systems of building design.

It is assumed that the proposed 5 or 6 storey wood-frame building will not be a high building as defined in the Building Code. A high building implies significantly more complex firefighting techniques which are outside the scope of this report. High buildings are defined in Division B, Clause 3.2.6.1.(1)(d) as buildings with the uppermost floor level is more than 18m above grade.

The authors also recognize that there are issues relating to the aging population and difficulty with evacuation; however, this is a separate topic applying to all buildings, combustible or noncombustible, not just 5 and 6 storey wood-frame buildings.

Alternative Solutions

This report relates to accepted solutions of Division B of the Code. This report is not intended to preclude Alternative Solutions to address elements outside the scope of this report, or different solutions to that provided in Division B. For example, this report is not intended to preclude Alternative Solutions for highrise buildings or other occupancies; it simply recommends Code changes in Division B to facilitate 5 and 6 storey wood-frame residential buildings.

2.0 Recommended Code Changes

This Section presents the recommended Code changes for permitting 5 and 6 storey wood-frame buildings of residential occupancy. The recommendations are aimed at addressing the technical and process risks associated with the Code change as identified in the Stage 1 Report. The Code change recommendations also takes into consideration the comments received during the Technical Advisory Group and Stakeholder's meetings held by BSPB. Subsections 2.1, 2.2 and 2.3 present the Code change recommendations relating to fire, structural and building envelope requirements of the Building Code, respectively.

For ease of reading the Code change recommendations, additions are identified by red and underlined fonts; deletions are identified by gray font; texts that are part of the current Code are left as unformatted texts.

2.1 Fire Safety (Part 3)

As stated in the Stage 1 Report, buildings are currently limited to 4 storeys due to restrictions in Division B, Part 3. In order to permit 5 and 6 storey wood-frame buildings of residential occupancy, Code changes are recommended for Part 3, in two aspects. First, Code change in Article 3.2.2.45 is recommended as the "core" Code change to explicitly permit 5 and 6 storey combustible constructions of Group C occupancy in Division B, Part 3. Second, additional Code changes are recommended to address the related technical and process risks due to the increase in building height as identified in the Stage 1 Report. It is noted that the Code change recommendations are aimed at 5 and 6 storey wood-frame buildings. However, as the principles of fire engineering generally apply to all combustible buildings, it may be appropriate to adopt the Code change recommendations for all combustible buildings. For discussion purposes, Table 1 is a summary of recommended Code changes for Division B, Part 3. The text of the recommended Code changes is presented as follows.

Table 1
Summary of the recommended Code changes for Division B, Part 3.

Item	Issue	Solution Proposed by the Code Change	Division B Reference
1	Building height	Permit 5 and 6 storeys.	3.2.2.45.(1)
2	Building area	Limit building area to 5 storey at 1440 m^2 and 6 storey at 1200 m^2.	3.2.2.45.(1)
3	Building shrinkage	An appendix note reminding designers that design of 5 and 6 storey wood-frame buildings shall include consideration for shrinkage.	A-3.2.2.45.(1)
4	Qualification of designers	An appendix note stating the need for qualified professionals and Best Practices Guides.	A-3.2.2.45.(1)
5	Fire rated floor assembly	Increase reliability of floor FRR	3.2.2.45.(5)
6	Fire rated floor assembly	An appendix note explaining the intent of item 5.	A-.2.2.45.(5)
7	Limitation on building physical height	Uppermost storey shall not exceed 18 m.	3.2.2.45.(6)
8	Exterior cladding	Noncombustible exterior cladding. Combustible cladding permitted only if it meets CAN/ULC-S134, or vinyl on GWB cladding. Also explicitly permit use of wood nailing elements when conditions are met.	3.1.4.1.(1), (3), (4), (5), and (6)
9	Use of horizontal exit	Permit the required exits in a floor area to be entirely consists of horizontal exits, if the exits lead to a floor area that has exit stairs.	3.4.1.6.(1) and (3)
10	Use of hold-open device	Permit use of hold open devices for horizontal exits.	3.1.8.12.(1)
11	Balcony sprinkler	Sprinklers in balconies exceeding 600 mm in depth.	3.2.5.13.(9)
12	Vertical concealed spaces	Address fire spread in vertical concealed spaces.	3.1.11.5.(3)
13	Exit fire separation	Increase reliability of exit fire separation.	3.4.4.1.(4)
14	Exit fire separation	Appendix A note explaining the intent of Item 14.	A-3.4.4.1.(4)
15	Limited ULC tested designs	Permit in Appendix D-2.3.3. the use of double layer designs when supported by appropriate fire test data.	D-2.3.3.(4)
16	Reference to NRC documents	Add to the current list of fire test reports in D-6.1. the NRC fire tests on floor and wall assemblies.	D-6.1

Recommended Code Change **Building Construction Requirement**
Sentence 3.2.2.45.(1)

3.2.2.45. Group C, up to 4 6 Storeys, Sprinklered

1) A *building* classified as Group C is permitted to conform to Sentence (2) provided

a) except as permitted by Sentences 3.2.2.7.(1) and 3.2.2.18.(2), the building is *sprinklered throughout*,

b) it is not more than 4 6 storeys in building height, and

c) it has a *building area* not more than

i) 7 200 m^2 if 1 *storey* in *building height,*
ii) 3 600 m^2 if 2 *storeys* in *building height*,
iii) 2 400 m^2 if 3 *storeys* in *building height*, or
iv) 1 800 m^2 if 4 *storeys* in *building height*,
v) 1 440 m^2 if 5 storeys in *building height,* or
vi) 1 200 m^2 if 6 storeys in *building height*.

(See Appendix A.)

Functional Statement

None

Objective

None

Intent

To state the application of Sentence 3.2.2.45.(2).

Rationale

Article 3.2.2.45 is the existing construction Article for combustible buildings of residential occupancy up to 4 storeys. It is recommended that the Code change to permit 5 and 6 storey wood-frame buildings be provided in Article 3.2.2.45. Article 3.2.2.45 is considered as the more appropriate Article as the Article has been established for combustible construction of Group C occupancy. The Code currently divides Group C construction into several categories; the key categories include 2 hour rated noncombustible, any area, any height; 1 hour rated noncombustible, 6 storey, up to 6000 m^2; 1 hour rated combustible, 4 storey, up to 1800 m^2; and the low-rise categories (1 to 3 storeys). As Code users are already familiar with the construction categories, it would be natural to amend the Code in Article 3.2.2.45, which is the 4 storey combustible construction category.

As discussed in the Stage 1 Report, Article 3.2.2.45 currently employs a formula in apportioning building area relative to the building height, such that the resulting gross floor area is limited to a maximum of 7200 m^2:

1 storey × 7200 m^2 = 7200 m^2
2 storey × 3600 m^2 = 7200 m^2
3 storey × 2400 m^2 = 7200 m^2
4 storey × 1800 m^2 = 7200 m^2

It is recommended that the total floor area of 7200 m^2 currently in existence be kept for the 5 and 6 storey clauses. Namely, allowing 5 storeys at 1440 m^2 and 6 storeys at 1200 m^2 in Sentence (1):

5 storey × 1440 m^2 = 7200 m^2
6 storey × 1200 m^2 = 7200 m^2

By maintaining the same gross building area, the technical risks as identified in the Stage 1 Report will not likely increase; namely:

- Risk of ignition
- Risk of interior fire spread beyond point of origin
- Risk of fire spread to neighbouring buildings
- Risk of failure of sprinkler system to control fire
- Risk of occupants not able to recognize fire
- Risk of occupants not able to evacuate the building, and
- Risk of fire service unable to conduct effective operation

This is because given the same gross floor area and the same fire engineering philosophy of compartmentalization and sprinkler protection, the probability of fire occurring and the consequential losses would not change. Any risks not identified by the Code due to the use of combustible material in construction is addressed by limiting the building area to 20% of that permitted for noncombustible building.

As discussed in the Stage 1 Report, the 7200 m^2 area is selected by NRC which is intended to limit the building area of combustible buildings to 20% of that of noncombustible buildings. There are no apparent engineering principles on the selection of the 20%; however, it has been generally accepted by the public of BC as the Code has been amended through several Code change cycles. Given there is no technical substantiation at this stage to increase or decrease the 20%, the 20% is recommended in order to maintain the same level of performance that has been deemed as acceptable by the BC public.

Recommended Code Change **Building Construction Requirement**
Appendix A A-3.2.2.45.(1)

A-3.2.2.45.(1) 5 and 6 Storey Wood-Frame Buildings

With respect to 5 and 6 storey wood-frame buildings, care must be taken by designers to properly address shrinkage so that deterioration caused by drying will not affect the health and safety of building uses, intended use of building, or operation of building services. See 5.1.4.2. The structural engineer is required to identify building movement due to shrinkage to the design team and this should be coordinated amongst design professionals for their respective responsibilities in Division B, Parts 3, 4, 5, 6, and 7.

In addition, there are elements of 5 and 6 storey wood-frame buildings that require specialist expertise in addressing various issues such as including but not limited to fire separations, fire blocking, exterior fire spread, and mixed occupancies. Further, some local governments may not have the expertise required for building review or may not wish to accept such risks. The involvement of a specialist engineer or architect with fire engineering expertise, as well as "Best Practices Guides" currently under development will further address these issues.

Functional Statement

Not applicable

Objective

Not applicable

Intent

Not applicable

Rationale

The Appendix A notes above are recommended to address process risks identified in the Stage 1 Report.

Part 5 and the standards referenced by Part 4 specifically address concerns with shrinkage. Part 3 has no specific requirements for addressing environmental concerns. Part 5 addresses shrinkage, in 5.1.4.2. However, Part 5 is limited to the building exterior and the assemblies separating dissimilar environments. In the case of building structure, dissimilar environment is the difference between the structure environment and the completed building environment, notwithstanding this dissimilar environment must be addressed. It would appropriate to address this in Part 5 except Part 5 is limited to building envelopes and dissimilar environments after construction. A requirement to consider shrinkage would be inappropriate in Part 3. Therefore, the Appendix A note is recommended here to reminder designers the need to coordinate the effects of shrinkage in the design of 5 and 6 storey buildings

With respect to the standard of care expected of design professionals for 5 and 6 storey wood-frame buildings, currently there is no specific qualification of fire engineer although guidelines are being prepared by APEGBC. A fire engineer specialist is not recommended at this time as a requirement based on consultation with APEGBC. However, it is recommended in the Appendix A note that engineers and architects with specialized expertise in fire be involved in 5 and 6 storey projects; these persons can provide advise and take liability that local governments may not be willing to accept. Finally, when "Best Practices Guides" relating to 5 and 6 storey wood-frame buildings are released, they would represent the standard of care expected of design professionals for 5 and 6 storey wood-frame buildings.

Recommended Code Change **Building Construction Requirement**
Sentence 3.2.2.45.(5)

3.2.2.45. Group C, up to ~~4~~ 6 Storeys, Sprinklered

5) In a *building* that is permitted by Sentence (1) to be 5 or 6 storey in *building height*, the *fire-resistance rating* required in Clause (2)(b) and (c) shall be derived based on a minimum of 2 layers of gypsum wallboard on the underside if the assembly incorporates gypsum wallboard.

(See Appendix A.)

Functional Statement

F03, F04

Objective

OS1.2, OS1.3, OP1.2, OP1.3

Intent

To limit the probability of wallboard based floor assemblies being installed incorrectly during construction or damaged during the course of the building's lifetime.

To limit the probability that wallboard based floor assemblies exposed to fire will prematurely fail or collapse during the time required to achieve occupant safety and for emergency responders to perform their duties, which could lead to harm to persons.

Rationale

Sentence (5) is recommended to address reliability of the FRR in floors and mezzanines when the assemblies utilize GWB as the means of deriving the fire-resistance. Reliability is not an area of building construction addressed by the 2006 BCBC. There is also no proposal in the 2010 NBCC at this point to address reliability based on our review. However, it is recommended that additional measures be taken to address reliability of GWB-based floor assemblies, which is a process risk identified and further discussed in the Stage 1 Report. Participations in BSPB's Technical Advisory Group meetings by the authors in September and October, 2008 have also indicated that the fire engineering and regulatory communities are general supportive of this concept.

Recommended Code Change Appendix A A-3.2.2.45.(5)	Building Construction Requirement Item 7 of Table 1

A-3.2.2.45.(5) Reliability of Membrane-Based Fire Separations

There is a concern with reliability of light-wood framing protected with a single layer gypsum wallboard membrane. Experience and testing by NRC have shown that two layer gypsum wallboard designs provide a high level of reliability and resistance to damage and installation error. This requirement is not intended to preclude use of tested designs that provide an appropriate degree of fire-resistance in the event of failure of the membrane.

Functional Statement

Not applicable

Objective

Not applicable

Intent

Not applicable

Rationale

It is recommended that the Appendix A notes above be included to explain the intent of the recommended Sentence 3.2.2.45.(5) and Sentence 3.4.4.1.(4).

Recommended Code Change **Building Construction Requirement**
Sentence 3.2.2.45.(6)

3.2.2.45. Group C, up to 4 6 Storeys, Sprinklered

6) In a *building* that is permitted by Sentence (1) to be 5 or 6 storeys in *building height*, the *building* shall not be more than 18 m in height, measured between *grade* and the floor level of the top *storey*.

Functional Statement

None

Objective

None

Intent

To state the application of Sentence 3.2.2.45.(6).

Rationale

Sentence (6) is recommended in order to prevent 5 and 6 storey wood-frame buildings from being built as a high building as defined by the Building Code. High buildings requirements assume interior firefighting, lengthier evacuation time and fire department access time. The requirements also deal with stack effects which become more prominent in high buildings. Without further analysis, it is not recommended at this point to permit high buildings of wood-frame construction. The wording of the 18 m limitation is intended to be consistent with current approach to high buildings in the Code. That is, allow construction requirements in Subsection 3.2.2. to determine the building height based on number of storeys and allow the 18 m criteria to the floor of the 6th storey to determine high building requirements. High building requirements are intended to address the risks associated with high buildings and are currently provided in the Code in an 'additional requirement' format (that is, Subsection 3.2.6 in addition to Subsection 3.2.2 requirements). This means Code application is currently used for 6 storey noncombustible buildings, and it is intended to keep the approach consistent, on the basis that the risk associated with combustible construction is addressed in Subsection 3.2.2.; the selection of the high building definition (ie. the 18 m) should not be based on whether the building is combustible or noncombustible at this point. As presented in the Stage 1 Report, the risks not contemplated by the Code objectives are addressed by limiting the building area to 20% of that of a noncombustible building.

Recommended Code Change **Building Exterior Cladding**
Article 3.1.3.1

3.1.4.1. Combustible Materials Permitted

1) Except as required by Sentences (3), (4) and (6), ~~A~~a *building* permitted to be of *combustible construction* is permitted to be constructed of *combustible materials*, with or without *noncombustible* components.

Functional Statement

None

Objective

None

Intent

To clarify that Part 3 buildings of combustible construction may be built with combustible materials, with or without noncombustible components, except the exterior wall construction for 5 and 6 storey combustible buildings.

To State the application of Sentences 3.1.4.1.(3), (4) and (6).

Rationale

The Code currently permits in Sentence 3.1.4.1.(1) combustible buildings to be constructed of combustible material. Notwithstanding this, for 5 and 6 storey wood-frame buildings, combustible exterior cladding would attribute to an increase in risk of exterior fire spread (see further discussion in the Stage 1 Report). It is therefore recommended that the use of combustible material on the exterior wall be limited by requiring the construction to conform to the proposed Sentences (3), (4) and (6).

Recommended Code Change **Building Exterior Cladding**
Sentence 3.1.4.1.(3)

3.1.4.1. Combustible Materials Permitted

3) Exterior cladding on a 5 or 6 *storey building* permitted in Sentence 3.2.2.45.(1) shall be *noncombustible*, except as permitted in Sentence (4).

Functional Statement

F02, F03

Objective

OS1.2, OP1.2

Intent

To limit the probability that combustible exterior cladding on a 5 or 6 storey combustible building will contribute to the spread of fire through the exterior of the building.

Rationale

Sentence (3) is recommended as a ‘default’ measure, where 5 and 6 storey buildings shall have noncombustible exterior cladding. See also recommended Code changes Sentence 3.1.4.1.(4) and (6).

Recommended Code Change **Building Exterior Cladding**
Sentence 3.1.4.1.(4)

3.1.4.1. Combustible Materials Permitted

4) Except for an *exposing building face* required by Article 3.2.3.7. to be *noncombustible*, the exterior wall in a 5 or 6 storey *building* permitted in Sentence 3.2.2.45.(1) is permitted to be clad with *combustible* cladding provided

a) the exterior wall assembly is constructed such that

i) the interior surfaces of the wall assembly are protected by a thermal barrier conforming to Sentence 3.1.5.12.(3), and

ii) the wall assembly satisfies the criteria of Sentences 3.1.5.5.(2) and (3) when subjected to testing in conformance with CAN/ULC-S134, "Fire Test of Exterior Wall Assemblies", or

b) the exterior wall assembly consists of vinyl siding over gypsum wallboard cladding.

Functional Statement

None

Objective

None

Intent

To exempt certain combustible materials from the application of Sentence 3.1.4.1.(3) if certain conditions are met, on the basis that the materials are deemed to insignificantly contribute to fire growth and spread.

Rationale

Sentence (4) is recommended to permit certain combustible exterior cladding if the exterior wall is not otherwise required by Article 3.2.3.7 to be noncombustible for exposure protection purposes. When not restricted by Article 3.2.3.7, it is recommended to permit two classes of combustible exterior cladding systems.

The first is if the exterior wall meets CAN/ULC-S134 "Fire Test for Exterior Wall Assemblies". This category of exterior wall system is taken from current Article 3.1.5.5. which permits combustible exterior walls that meets the S134 test in noncombustible buildings. This test distinguishes certain combustible claddings, which have an acceptable resistance to fire spread on exterior of a building. It is noted here that the application of Sentence 3.1.5.5.(1) for noncombustible buildings is limited to exterior non-loadbearing walls; this has however been omitted in our recommendation for Sentence 3.1.4.1.(4) for combustible buildings.

The second is if the exterior wall consists of vinyl siding over GWB cladding. This recommendation is based on practical consideration that vinyl is commonly used as an exterior cladding. A vinyl over GWB cladding system has been found to provide an acceptable level of exterior fire spread based on the test conducted at NRC by Oleszkiewicz[1]. The NRC test predates the CAN/ULC-S134 standard and is the test for which the S134 standard is derived from. Based on our review of the test results presented by NRC, we recommend permitting vinyl on GWB as an acceptable exterior cladding system, in addition to the CAN/ULC-S134 test avenue. In view that the building is fundamentally permitted to be combustible, and that the building areas are kept to 20% of a noncombustible building, the recommendations for use of combustible cladding as discussed above is considered reasonable.

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[1] Oleszkiewicz, I., Fire and Combustible Cladding, http://irc.nrc-cnrc.gc.ca/pubs/cp/fir1_e.html (last visited October 27, 2008), Institute for Research in Construction, National Research Council Canada, Ottawa, Canada.

Recommended Code Change **Building Exterior Cladding**
Sentence 3.1.4.1.(5)

3.1.4.1. Combustible Materials Permitted

5) A wall assembly permitted by Sentence (4) that includes *combustible* cladding of *fire-retardant-treated wood* shall be tested for fire exposure after the cladding has been subjected to an accelerated weather test as specified in ASTM D 2898 "Accelerated weathering of Fire-Retardant-Treated Wood for Fire Testing."

Functional Statement

None

Objective

None

Intent

To clarify that the wall assembly must be subjected to weathering tests before the fire tests to limit the probability that the weathering of the material will negatively affect its ability to minimize fire growth and spread.

Rationale

Sentence (5) is recommended for reasons of consistent application of the Code in Sentence 3.1.5.5.(4).

Recommended Code Change **Building Exterior Cladding**
Sentence 3.1.4.1.(6)

3.1.4.1. Combustible Materials Permitted

6) *Combustible* nailing elements supporting exterior cladding permitted in Sentence (3) and Clause (4)(a) are permitted, provided the horizontal air space created by the nailing elements does not exceed 25 mm.

Functional Statement

None

Objective

None

Intent

To exempt Application of Sentence 3.1.4.1.(3), which would otherwise require noncombustible exterior cladding, on the basis that the air space of 25 mm would be acceptable in limiting the probability of fire spread along the exterior wall.

Rationale

Sentence (6) is recommended to permit practical use of wood nailing elements (wood strapping), provided that the cavity (typically the rain screen) formed by the wood nailing elements is less than 25 mm in thickness. The 25 mm thickness is intended to be consistent with Clause 3.1.11.2.(2)(d).

Recommended Code Change **Use of Horizontal Exits**
Sentence 3.4.1.6.(1)

3.4.1.6 Restricted Use of Horizontal Exits

1) Except as permitted by Sentences (2) and (3), *horizontal exits* shall not comprise more than one half of the required number of *exits* from any *floor area*.

Functional Statement

F10

Objective

OS3.7

Intent

To limit the probability that persons will not have a choice of sufficient alternative exterior exit routes in the event that routes to horizontal exits are blocked or obstructed in an emergency situation, which could lead to delays in the evacuation or movement of persons to a safe place, which could lead to harm to persons.

Rationale

Modification to Sentence 3.4.1.6.(1) is recommended to also include exception for the proposed Sentence (3), which is specifically written for 5 and 6 storey wood-frame buildings.

Recommended Code Change | **Use of Horizontal Exits**
Sentence 3.4.1.6.(3)

3.4.1.6 Restricted Use of Horizontal Exits

3) In a 5 or 6 storey building of residential occupancy permitted by Sentence 3.2.2.45.(1), *horizontal exits* can comprise all of the required number of *exits* from a *floor area* provided

a) doors of the *horizontal exits* are designed in conformance with Sentences 3.1.8.12.(2), (3) and (4), and

b) the *horizontal exits* lead to a *floor area* that does not have *horizontal exits* comprising more than one half of the required number of *exits* in that *floor area*.

Functional Statement

F10, F05

Objective

OS3.7

Intent

To supersede the requirements of Sentence 3.4.1.6.(1) and permit an increase in the ratio of horizontal exits to all exits to 100% for 5 and 6 storey combustible buildings on the basis that:

- 5 and 6 storey combustible buildings will be limited in building area such that the travel distance will be limited,
- such buildings are fully sprinklered, and
- the horizontal exits will lead to another building where there will be exit stairs within reasonable travel distance.

Rationale

Horizontal exits are currently restricted in Sentence 3.4.1.6.(1) to comprise up to one half (50%) of the required exits from a floor area. The intent is that the other 50% of the required exits would be a type of exit, typically an exit stair, that leads occupants to an exterior open space or public thoroughfare. Although not a specific Code objective released by NRC, it is also generally agreed by the fire engineering community that exits are also used for Fire Department access to floor areas. Therefore, having mandatory limitation on horizontal exits implicitly demands a certain number of exit stairs per building, which limits the travel distance for fire department access to a floor area.

In view of the smaller building area to be permitted for 5 and 6 storey wood-frame buildings, Sentence (3) is recommended to permit the required exits to be comprised entirely of horizontal exits, provided that the horizontal exits lead to a floor area where horizontal exits do not comprise more than one half of the required number of exits in that area. By placing the limitation in Clause (b), occupants may be in a building where there are no exit stairs; however, they would have access to exit stairs within the floor areas immediately across the firewall. This is schematically illustrated in Figure 1. As shown, the separation distance between exit stairs will remain unchanged provided all buildings across the firewall are of the same building area. In our opinion, given the decrease in occupant load per floor and travel distance as a result of smaller building area, the reliance on horizontal exits in a building which is attached to buildings with exit stairs would not subject occupants to an undue level of risk beyond that accepted by the current Code.

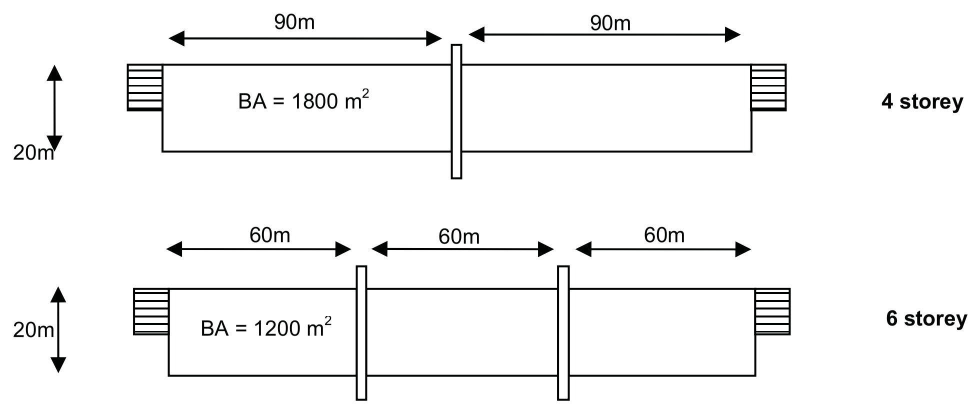

Figure 1. Schematic illustration of a typical 4 and 6 storey building layout.

Recommended Code Change **Use of Hold Open Devices**
Sentence 3.1.8.12.(1)

3.1.8.12 Hold-Open Devices

1) A hold-open device is permitted on a door in a required *fire separation*, other than an *exit* *stair* door in a *building* more than 3 *storeys* in *building height*, and on a door for a vestibule required by Article 3.3.5.7., provided the device is designed to release the door in conformance with Sentences (2), (3) and (4).

Functional Statement

F03

Objective

OS1.2

Intent

To exempt certain doors from the application of Sentence 3.1.8.11.(1), which would otherwise require the door to be closed after each use, if certain conditions are met to automatically close the door under fire conditions. This is to limit the probability that fire will spread from one fire compartment to another fire compartment, which could lead to harm to persons in the other fire compartment.

To state the application of Sentences 3.1.8.12.(2), (3) and (4).

Rationale

This Code change is taken from NRC's proposed Code change for the 2010 NBC (NRC Reference: NBC05-03.01.08.12.(01)-FP,UE-V3_ed.doc). Use of hold-open devices in exits have traditionally been limited to 3 storey buildings based on the assumption that stack effects would render the devices ineffective when releasing the door in a fire emergency. However, this requirement is intended to address exit stairs, where the stair shaft is a high vertical compartment, which is more susceptible to staff effects. On the other hand, firewall closures are not likely to be subjected to stack effects as it not typically installed in a high vertical space setting. The 2010 Code change proposal clarifies this understanding by adding the term 'stair' to the existing Sentence.

It considered that in 5 and 6 storey wood-frame buildings, due to the limitation in building area, firewalls will likely be used. It has been observed, and as also supported by the NRC Code change proposal, that firewall closures (horizontal exit doors) are frequently wedge or prop open for convenience purposes, compromising the integrity of the exits. In view of this, it is proposed to permit hold-open devices as proposed by NRC at this time such that unwanted alternation or obstruction that affect the proper functioning of horizontal exits can be addressed.

This recommended Code change is not specifically limited to 5 and 6 storey wood-frame buildings as NRC is proposing the Code change for all buildings.

Recommended Code Change **Automatic Sprinkler Systems in Balconies**
Sentence 3.2.5.13.(9)

3.2.5.13 Automatic Sprinkler Systems

9) Notwithstanding Sentence (1), for a 5 or 6 storey *building* permitted in Sentence 3.2.2.45.(1), automatic sprinkler protection shall be provided for all unenclosed exterior balconies where the depth of the balcony is more than 600 mm.

Functional Statement

None

Objective

None

Intent

To provide fire protection to balconies where substantial quantities of combustibles may be stored, so that fire spread from one storey to another is inhibited.

Rationale

As identified in the Stage 1 Report, in a 5 or 6 storey wood-frame building, there would be an increase in risk of exterior fire spread. The risk of ignition will not likely increase; however, the consequential loss would be greater should exterior fire spread occur. In order to address this risk, Sentence (9) is recommended to require mandatory sprinklering of balconies that are more than 600 mm in depth. The selection of the 600 mm depth is based on the current provision contained in Division B, Sentence 3.2.5.13.(9) of the City of Vancouver Building Bylaw 2007, which is used as the criteria in determining when substantial quantities of combustibles may be stored in balconies. The rationale to Sentence 3.2.5.13.(9) of the Vancouver Building Bylaw 2007 can be found on the City of Vancouver web site at http://vancouver.ca/ctyclerk/cclerk/020801/csb2.htm (last visited October 27, 2008).

Recommended Code Change **Fire Stopping of Concealed Spaces**
Sentence 3.1.11.5.(3)

3.1.11.5. Fire Stopping of <~~Horizontal~~ Concealed Spaces>

3) Any vertical concealed space in or attached to a 5 or 6 *storeys* building permitted in Sentence 3.2.2.45.(1) shall be separated by construction conforming to Article 3.1.11.7. into compartments such that the maximum vertical dimension is not more than 3 m and the maximum horizontal dimension is not more than

a) 20m if the exposed construction materials within the space have a *flame-spread rating* not more than 25, or

b) 10m if the exposed construction materials within the space have a *flame-spread rating* more than 25.

Functional Statement

F03, F04

Objective

OS1.2, OP1.2

Intent

To limit the probability that certain vertical concealed spaces will not be separated from certain other parts of the building, which could lead to the spread of fire within these spaces, which could lead to harm to persons.

To limit the probability that fire stopping material used to block and separate certains paces will not remain in place for a certain minimum time when subjected to fire conditions, which could lead to the spread of fire within these spaces, which could lead to harm to persons.

To state the application of Article 3.1.11.7.

Rationale

Unprotected concealed spaces are known to cause rapid fire spread. Tall wood buildings with unprotected vertical concealed spaces are particularly vulnerable as they would contribute to rapid spread of fire between storeys. The Code already consists of provisions to Subsection 3.1.11 to address concealed spaces and the need for fire stopping and fire blocking. However, review of the Code indicates that it does not explicitly address vertical concealed spaces. In view of the increased vulnerability of 5 and 6 storey wood-frame buildings with unprotected vertical concealed spaces, Sentence (3) is recommended to require fire blocking of concealed spaces into compartments. The selection of the compartment dimension is based on a fixed height of 3 m and a choice of width of 20 m or 10 m depending on the exposed surface in the concealed space. This would respectively result in volumes of 600 m^2 and 300 m^2 which are the currently established volumes in Sentence (1).

The foregoing rationale applies to all combustible buildings and it may be appropriate to extend the recommended Code change of Sentence (3) to all combustible buildings, and not just 5 and 6 storey wood-frame buildings.

Recommended Code Change **Fire-Resistance Rating of Exit Separations**
Sentence 3.4.4.1.(4)

3.4.4.1. Fire-Resistance Rating of Exit Separations

4) Where an *exit fire separation* is a gypsum wallboard based assembly in a 5 or 6 *storey building* permitted in Sentence 3.2.2.45.(1), the assembly shall consists of a minimum of 2 layers of gypsum wallboard on each side.

(See Appendix A.)

Functional Statement

F03, F05, F06

Objective

OS1.2, OS1.5, OP1.2

Intent

To limit the probability that fire will spread into an exit, which could lead to delays or ineffectiveness in fire emergency response operations, which could lead to the further spread of frie, which could lead to damage to the building.

To limit the probability that fire will spread from one floor area to another floor area by means of an exit, which could lead to damage to the building.

Rationale

Based on the comments received during the Technical Advisory Group meetings held by BSPB, there is a general concern with the reliability of an exit fire separation. It is viewed that the integrity of exits becomes significantly more important in 5 and 6 storey wood-frame buildings as they are the sole means of egress and access. In order to increase the reliability of exit fire separations, where the fire-rating of the fire separation is based on use of gypsum wallboard, it is recommended to require mandatory use of 2 layers of gypsum wallboard on each side of the separation.

Recommended Code Change **Fire-Resistance Rating of Exit Separations**
Appendix A A-3.4.4.1.(4)

A-3.4.4.1.(4) Reliability of Membrane-Based Exit Fire Separations

See A-3.2.2.45.(5).

Functional Statement

Not applicable

Objective

Not applicable

Intent

Not applicable

Rationale

It is recommended that the Appendix A note above be included to reference the recommended A-3.2.2.45.(5) notes on reliability of membrane-based fire separations.

Recommended Code Change | **Component Additive Method**
Appendix D D-2.3.3.

D-2.3.3. Limitations of Component Additive Method

3) Except as permitted in D-2.3.3.(4), ~~W~~wallboard membranes are permitted to be installed in multiple layers only as listed in Table D-2.3.4.A (double 12.7 mm Type X gypsum wallboard).

4) Wallboard membranes are permitted to be installed in multiple layers where appropriate fire test data is available to demonstrate the acceptability of the installation methods. Such fire tests include but not limited to the fire tests published by NRC, entitled "Results of Fire Resistance Tests on Full-Scale Floor Assemblies – Phase II".

Functional Statement

Not applicable

Objective

Not applicable

Intent

Not applicable

Rationale

The current component additive method provided in Division B, Appendix D limits its use to assemblies with one layer of gypsum wallboard, except as noted in Sentence (3). It is recommended to amend D-2.3.3. to include Sentence (4) such that design professionals and AHJs are explicitly informed that appropriate fire tests can be used to substantiate designs with two layers of gypsum wallboard based on Appendix D.

It is noted here that Appendix A is a list of standard assemblies for Part 9 whereas Appendix D is a part of the Code that provides further information for engineers to design building fire separations.

Recommended Code Change
Appendix D D-6.1.

Referenced Fire Test Reports

D-6.1. Fire Test Reports

(20) Sultan, M.A., Seguin, Y.P. and Leroux, P., Results of Fire Resistance Tests on Full-Scale Floor Assemblies, Internal Report IRC-IR-764, Institute for Research in Construction, National Research Council Canada, Ottawa, May 1998.

(21) Sultan, M.A., Latour, J.C., Leroux, P., Monette, R.C., Seguin, Y.P. and Henrie, J.P., Results of Fire Resistance Tests on Full-Scale Floor Assemblies – Phase II, Research Report IRC-RR-184, Institute for Research in Consturction, National Research Council Canada, Ottawa, March 2005.

(22) Sultan, M.A. and Lougheed, G.D., Results of Fire Resistance Tests on Full-Scale Gypsum Board Wall Assemblies, Internal Report IRC-IR-833, Institute for Research in Consturction, National Research Council Canada, Ottawa, August 2002.

Functional Statement

Not applicable

Objective

Not applicable

Intent

Not applicable

Rationale

The Code changes are recommended in D-6.1. to add to the list of references the IRC-NRC fire tests aimed at determining the fire-resistance of wall and floor assemblies.

2.2 Structural (Part 4)

The following are the recommended Code changes for structural aspects of the Building Code.

Recommended Code Change — **Defined Terms**
Division A, Sentence 1.4.1.2.(1)

1.4.1.2. Defined Terms

1) The words and terms in italics in this Code have the following meanings:

Designated structuraleEngineer (Struct. Eng.) means a person who is registered or licensed to practice as a professional engineer under the Engineers and Geoscientist Act, and a person who is designated by the Association of Professional Engineers and Geoscientists of British Columbia as a Designated Structural Engineer

Five and six storey wood-frame structures means buildings whose primary structural framing consists of wood for either the lateral or gravity resisting system and are designed in accordance with Division B Part 3 for combustible construction and Part 4 for structural design.

Rationale

The term Designated Structural Engineer (Struct. Eng.) needs to be defined as well as five and six storey wood-frame structures. These two terms will be used throughout in other sections of the Code.

Recommended Code Change | **Professional Design and Review**
Division B, Sentence 4.1.8.10.(3)

4.1.8.10 Additional System Restrictions

3) Except as required in Sentence (4), *building*s having fundaments lateral periods T_a of 1.0 s or greater and where $I_eF_vS_a(1.0)$ is greater than 0.25, walls forming part of the SFRS shall be continuous from their top to the foundation and shall not have irregularities of Type 4 or 5 as descried in Table 4.1.8.6.

4) For *five and six storey wood-frame structures* of any period and where IeFvSa(1.0) is greater than 0.25, walls forming part of the SFRS shall be continuous from their top to the foundation and shall not have irregularities of Type 4 or 5 as described in Table 4.1.8.6.

Rationale

At the current time, much work is required in reviewing appropriate seismic design requirements for five and six storey wood-frame buildings. Until this research can adequately address the effects of irregularity types 4 or 5, it will be conservative to require that shear walls are continuous from their roof to their base. This will discourage the practice of providing large open spaces on main or second floors for open spaces such as amenities. These areas will require that wood-frame shear walls not include in plane discontinuities or out of plane offsets. This may perhaps be relaxed at a later time pending the results of future research.

Recommended Code Change **Design Basis for 5 and 6 Storey Wood-Frame Structures**
Division B, Article 4.4.3

4.4.3 Five and Six Storey Wood-Frame Structures

4.4.3.1. Design Basis for Five and Six storey Wood-Frame Structures

1) The structural design for *five and six storey wood-frame structures* shall conform to CAN/CSA-O86.1-M "Engineering Design in Wood" and to "*APEGBC Guidelines for Professional Engineering Services on Five and Six Storey Wood-Frame Structures*" using the loads stipulated in Section 4.1., in accordance with limit states design in Subsection 4.1.3.

Rationale

For the first introduction of five and six storey residential structures into the building code, it is recommended that they be highlighted as a special structure. In addition to requiring the design conform to the Canadian Wood Code it is also recommended that the *APEGBC Guideline for Professional Engineering Services on Five and Six Tory Wood Frame Structures* be referenced. Currently, it is generally agreed upon by SEABC committee members reviewing considerations for higher wood frame buildings that special provisions are provided for in the design and construction of five and six storey wood-frame buildings. In practice, there are many process risks associated with the design and construction of such structures. The intent of the guide would be to ensure that these process risks would be appropriately dealt with, and guidance provided to assist engineers in design and construction requirements. Topics such as shrinkage, workmanship, load paths, and minimum drawing requirements would need to be addressed. As well, provisions for designing for lateral loads due to seismic and wind would need to be addressed. In addition, capacity design principals only now introduced into CSA086.1 2009 will need to be reviewed in lieu of taller building and likely modified to suit 5 and 6 story wood frames as well as be provided as part of the guide. It is generally agreed that the current practice for up to 4 stories will not be adequate for Five and Six stories. So it is important that such a guide be prepared in order to ensure the industry is appropriately prepared.

Although it is our opinion that the guide be in place prior to a code change and referenced from the code, the legal requirements of referencing and APEGBC guide within the code would and the timing of the Guidelines needs to be reviewed by the province and APEGBC.

A less desirable option at the discretion of the Province would be to have clause 4.4.3.1.1 reference the appendix A where the guide could be referenced. If the guide is not ready at that time, the commentary could be expanded to outline the process and technical risks and suggest that designers partaking in this work are responsible to ensure that the objective and functional statements outlined in Division B are met.

Recommended Code Change **Administrative Provisions**
Division C, Article 2.2.1.2

2.2.1.2. Structural Design

1) Except as required in Sentence (2) and (3), for design carried out in accordance with Part 4 of Division B, the *designer* shall be a *registered professional* skilled in the work concerned.

(See Appendix A.)

2) For the design of Part 3 – *five and six storey wood-frame structures* carried out in accordance with Part 4 of Division B, the designer shall be a registered professional who is designated by the Association of Professional Engineers and Geoscientists of British Columbia as a *designated structural engineer (Struct. Eng.)* and who

a) is retained to undertake the overall responsibility for the design work and field reviews of the primary structural components of a *five and six storey wood-frame structures* that falls within the scope of Article 1.3.3.2. of Division A,

b) shall apply his or her professional (P.Eng.) seal or stamp together with his or her *Struct. Eng* stamp, with signature and date to the plans and supporting documents prepared by, or under the supervision of the *designated structural engineer* in support of the building permit application, and

c) shall apply his or her professional (P.Eng.) seal or stamp together with his or her *Struct. Eng.* Stamp with signature and date to the Letters of Assurance descried in Division C, Subsection 2.2.7

3) For the concept review as defined by the Association of Professional Engineers and Geoscientists of British Columbia, the qualifications are to also require that the concept reviewer shall be a *registered professional* who is designated by the Association of Professional Engineers and Geoscientists of British Columbia as a *designated structural engineer (Struct. Eng.)*

Rationale

It is recommended that for this code cycle of five and six storey wood-frame structures that the Struct Eng designation be required. It is our opinion that load paths and proper detailing are essential to ensure that the gravity and lateral loads are adequately addressed. The current Struct Eng. Designation is generally considered a higher designation than P.Eng due to the additional qualifications required beyond what is required for the P. Eng designation. It is recommended that this higher designation be required at this time.

Wood frames structures have inherent strengths due to the nature of their form. However, this inherent strength reduces as these structures carry higher gravity and wind loads due to their increased height. A thorough understanding of load paths, appropriate design practices, and adequate detailing will be paramount. So until which time either the BCBC requires the Struct. Eng. Designation for all buildings, or it is otherwise felt that the industry is well versed in the challenges of the taller structures, requiring the higher designation of Struct. Eng. is recommended.

It is also recommended that the concept reviewer be a Designated Structural Engineer (Struct. Eng.) and that the **Province adopt a concept review schedule similar to that of Vancouver that has to be signed and sealed by the concept reviewer and submitted as part of the building permit package. This would affect all buildings and not be limited to just five and six storey wood-frame buildings.**

Recommended Code Change **Administrative Provisions**
Division C, Clause 2.2.4.3.(1).(f)

2.2.4.3. Information Required on Structural Drawings

3) Structural drawings and related documents submitted with the application to build shall indicate, in addition to those items specified in Article 2.2.4.6. and in Part 4 of Division B applicable to the specific material,

a) the name and address of the person responsible for the structural design,

b) the date of issue of the Code and standards to which the design conforms,

c) the dimensions, location and size of all structural members in sufficient detail to enable the design to be checked,

d) sufficient detail to enable the *dead loads* to be determined, and

e) all effects and loads, other than *dead loads*, used for the design of the structural members and exterior cladding.

f) total anticipated building shrinkage per floor and lateral wind and seismic drift per floor for *five and six storey wood-frame structures*.

Rationale

It is our recommendation that the practice for five and six storey wood-frame structures must require that the building movements due to shrinkage, as well as drift due to wind and seismic loads be clearly documented on the building plans. This will ensure that others involved are aware of the movements that must be accommodated for in the design and construction for five and six storey wood-frame structures. It is not the intent that these movements are not required to be provided for other structures, but we are specifically requesting that they be provided on the drawings for five and six storey wood-frame structures. We have been retained to only address 5 and 6 story wood frame structures but this requirement along with all other anticipated building movements should be applied to all buildings.

Recommended Code Change | **Third Party Field Review**
Clause 2.2.7.2.(1)(c)

2.2.7.2. Owner Responsibilities

1) Before an owner obtains a building permit from an *authority having jurisdiction*, the owner shall

a) retain a coordinating registered professional to coordinate all design work and field reviews of the registered professionals required for the project in order to ascertain that (See Appendix A.)

i) the design will substantially comply with the British Columbia Building Code and other applicable enactments respecting safety, and

ii) the construction of the project will substantially comply with the British Columbia Building Code and other applicable enactments respecting safety, not including the construction safety aspects, and

b) deliver to the *authority having jurisdiction* letters, in the forms set out in Schedules A, B-1 and B-2 (See the end of Division C) (See Appendix A)

c) retain an independent third party professional engineer to field review a representative sampling of vertical and lateral resisting elements and systems for *five and six stoery wood-frame structures* to ensure that the construction generally conforms to the signed and sealed construction documents for the representative area reviewed. This review is to cover representative details for 10% of the total primary structure. The *registered professional* engineer is to provide a signed and sealed letter to the *coordinating registered professional* stating that the work reviewed generally conforms to supporting documents. The extent of the work reviewed is to be indicated. Where deficiencies in construction are noted, a letter is to be provided within 1 day of the review to the *engineer of record* and *registered coordinating professional* indicating the nature of the deficiencies.

Rationale

It is recommended at least for the first code cycle of this change that a 3rd party independent review be provided for five and six storey wood-frame structures to independently ascertain that the representative areas reviewed generally conform with the construction documents. It may be possible to eliminate this clause once it is generally agreed that the level of field reviews being provided is adequate.

2.3 Building Envelope (Part 5)

As presented in the Stage 1 Report, there is no recommended Code change for Part 5 to permit 5 and 6 storey wood-frame buildings of residential occupancy, as Part 5 is a performance-based Code.

CONCLUSION

This Stage 2 Report provides the recommended Code changes to the current 2006 BCBC with respect to fire safety and structural design requirements. No building envelope Code changes are recommended as Division B, Part 5 is a performance-based Code. The Code change recommendations are developed with the objective to permit the design and construction of 5 and 6 storey wood-frame buildings and address the associated technical and process risks, which are identified in the Stage 1 Report. Code change recommendations provided for fire are confined to Division B, Part 3, whereas for structural changes are recommended to Division A for defined terms, Division B Part 4 and Division C for administrative requirements. The Code change recommendations provided in this report shall not be construed as being exhaustive. We understand the recommendations will be made available to the BC public as part of the public consultation process.

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TECHNICAL AND PROCESS RISKS IN 5 AND 6 STOREY WOOD-FRAME BUILDINGS OF RESIDENTIAL OCCUPANCY

Prepared for

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January 19, 2009

GHL File BSP-3517.00

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DISCLAIMER

This technical report is prepared by **GHL** CONSULTANTS LTD (GHL) for the Ministry of Housing and Social Development. The purpose of this report is to provide a professional opinion to the Ministry on the proposed Code change to permit up to and including 6 storey wood-frame buildings of residential occupancy. The formulation of GHL's opinion is based on the science of fire engineering and a review of the available literature and is inherently limited by the short timeframe (September - November, 2008). Work of this nature would normally require substantial research for a significantly greater duration. GHL's work shall not be construed as exhaustive. There may be other relevant considerations for the Code change proposal not identified by GHL. At the time of report writing, GHL has recommended that BSPB retain qualified professionals to address other requirements such as including, but not limited to, construction fire safety, as well as electrical and mechanical systems of building design. Additionally, it is understood that a public consultation process has been carried-out in conjunction with this report. The BC Government shall be solely responsible for the act of amending the BC Building Code to permit 5 and 6 storey wood-frame buildings of residential occupancy, or making any changes to any provisions in the Building Code. It is the BC Government's sole discretion to adopt, consider or accept, in part or in full, the work of GHL contained in this report. GHL shall not be responsible for any loss of any kind that may arise due to any construction, building, or structure as a result of GHL's work or any Building Code or construction regulation change. Should this report be made available to other organizations that have regulatory capacity in construction of buildings and structures, this disclaimer shall equally apply. By preparing this report, GHL does not express explicitly or implicitly any social, economical or political opinion, or any other non-technical opinion, as it relates to the Code change proposal. This report is intended to be purely technical in nature. Any inquiries on this report shall be directed to the Ministry:

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1.0 BASIS OF REPORT

Background

GHL Consultants Ltd (GHL) has been requested by the Building Safety and Policy Branch (BSPB) of the Ministry of Housing and Social Development to prepare this technical report for the Mid-Rise Wood-Frame Residential Construction project. The scope of this report is to identify and comment on the process and technical risks relating to the Code change to permit 5 and 6 storey wood-frame buildings in BC, specifically focusing on fire safety requirement of Division B, Part 3 of the Code. It is the BC Government's responsibility to ensure that all aspects of the Building Code are appropriately addressed in amending the Building Code.

Definition of Risks

- **Technical Risk**
  Technical risk is defined by BSPB to mean: *exposure to loss arising from activities such as design, engineering, and construction processes and includes the following risk areas: fire safety, seismic, structural shrinkage, sound transmission, building techniques, moisture, material shrinkage, etc.* In general terms, with respect to fire safety, this can be paraphrased to mean the level of risk associated with a building that is built in full compliance with Part 3 of Division B without significant defect.

- **Process Risk**
  Process risk is defined by BSPB as to mean: *processes that are not clearly defined, are poorly aligned with business objectives and strategies, do not satisfy stakeholders' needs, or* expose *assets to misappropriation or misuse. Process risk includes the following risk areas: industry readiness and competency in areas of both design and construction, readiness of warranty providers to provide insurance in accordance with Homeowner Protection Act, Fire Department capabilities, etc.* In general terms, this can be paraphrased to mean practical concerns with constructing a 6 storey combustible building of residential occupancy – the risks associated with the unavoidable inability for the industry to deliver a building that is in full compliance with the BC Building Code.

Methodology

We have identified the technical risks based strictly on the fire safety objectives of the Building Code. Analysis of the technical risks is based on a qualitative approach, whereby the risk associated with a 5 or 6 storey wood-frame building is compared to that of a 4 storey wood-frame or 6 storey light steel-frame building. No quantitative risk analysis was performed, given that the National Building Code of Canada and the adopted BC Building Code are not written based on a quantitative risk analysis.

The process risks are identified based in part on GHL's professional experience, as well as input received from the Technical Advisory Group meetings held by BSPB during the period of September - November, 2008. GHL has also reviewed the joint AIBC and APEGBC letter submitted to BSPB regarding technical considerations for the proposed Code change.

Assumptions

- **Combustible Construction**
  The work presented in this report assumes traditional wood-frame construction employed in BC as requested by BSPB; however, with respect to Part 3 of Division B, the term "combustible construction" is used in the Code, as Part 3 only distinguishes construction as being "combustible" or "noncombustible". Typical combustible construction in BC is "platform framing" construction, or commonly known as wood-frame construction. It should be noted, however, that combustible construction could potentially include other types of combustible material and that GHL has only been retained to address conventional BC wood-frame construction.

- **The Building Code**
  The terms "Building Code" and "Code" in this report generally refer to the British Columbia Building Code 2006 (BCBC) unless otherwise indicated. The BCBC 2006 is based on the National Building Code of Canada 2005 (NBCC) with no substantial changes related to this project.

- **Alternative Solutions**
  This report relates to accepted solutions of Division B of the Code. This report is not intended to preclude Alternative Solutions to address elements outside the scope of this report, or different solutions to that provided in Division B.

2.0 RISK ANALYSIS

Technical Risks

The BC Building Code is essentially a consensus document that regulates construction standards in the Province of BC. The Codes are written and revised through each NBCC Code change cycle in an effort to better manage risks in buildings. As an objective-based Code, the BC Building Code 2006 objectives, which are found in Section 2.2 of Division A, identify the risk areas that the Code recognizes. The required level of performance with respect to each Code objective is then set out in the acceptable solutions in Division B. The acceptable solutions define the boundary between "acceptable" and "unacceptable" risks and are used to evaluate alternative solutions. In this regard, a "Code compliant" or "Division B complaint" building does not mean the building is risk-free; rather, it means that the risks have been managed to a level that is deemed acceptable.

As discussed, it is not possible to provide a quantitative risk analysis to compare the risk levels numerically, given that it is not the basis on which the Code was developed. If a quantitative approach is to be taken, it would be an immense undertaking in that every aspect of the Code would need to be re-assessed quantitatively. In many instances, this task may be very difficult, if not impossible, to carry-out; however, it is possible to provide a risk assessment based on a qualitative approach. Recognizing that Division B defines the boundary between acceptable and unacceptable risks, one may approach the project by comparing a 5 or 6 storey wood-frame building to other types of construction already contained in Subsection 3.2.2 of Division B. This means of analysis is appropriate and is the approach often employed when alternative solutions are developed. Further discussion on qualitative risk analysis and development of alternative solutions is found in Appendix A A-1.2.1.1.(1)(b) of the Code.

In a qualitative risk analysis, the steps are generally as follows:

1. Identify the objectives of the Division B requirements; this identifies which risks are relevant.
2. Evaluate the level of performance of the Division B requirement in achieving the objectives of the Division B requirements.
3. Evaluate the performance of the alternative solution relative to the objective.
4. Compare the performance between the Division B solution and the alternative solution.

For the 6 storey wood-frame project, the same approach was taken. In our analysis, we compared a 6 storey wood-frame building to a 4 storey wood-frame and a 6 storey light steel-frame building of residential occupancy, which are 1h fire rated buildings defined in Subsection 3.2.2 of Division B.

We begin the risk analysis by summarizing the risk areas that are defined by the fire safety objectives of the Code, which are listed below.

- **OS1 Fire Safety**
  An objective of the Code is to limit the probability that, as a result of the design or construction of the building, a person in or adjacent to the building will be exposed to an unacceptable risk of injury due to fire. The risks of injury due to fire addressed in the Code are those caused by:

  OS1.1 Fire or explosion occurring
  OS1.2 Fire or explosion impacting areas beyond its point of origin
  OS1.3 Collapse of physical elements due to a fire or explosion
  OS1.4 Fire safety systems failing to function as expected
  OS1.5 Persons being delayed in or impeded from moving to a safe place during a fire emergency

- **OP1 Fire Protection of the Building**
  An objective of the Code is to limit the probability that, as a result of its design or construction, the building will be exposed to an unacceptable risk of damage due to fire. The risks of damage due to fire addressed in this Code are those caused by:

  OP1.1 Fire or explosion occurring
  OP1.2 Fire or explosion impacting areas beyond its point of origin
  OP1.3 Collapse of physical elements due to a fire or explosion
  OP1.4 Fire safety systems failing to function as expected

- **OP3 Protection of Adjacent Buildings from Fire**
  An objective of the Code is to limit the probability that, as a result of the design or construction of the building, adjacent buildings will be exposed to an unacceptable risk of damage due to fire. The risks of damage to adjacent buildings due to fire addressed in this Code are those caused by:

  OP3.1 Fire or explosion impacting areas beyond the building of origin

From these objectives, the technical risks can be established as summarized in Table 1 below. Again, there may be other technical risks that are not addressed by the current BC Building Code 2006; however, they are outside the scope of GHL's work and are not specifically recognized by the Code.

Table 1. Technical risks on fire safety addressed by the BC Building Code 2006.

TECHNICAL RISK	CODE OBJECTIVE
Ignition	OS1.1, OP1.1
Fire spread beyond point of fire origin	OS1.2, OP1.2
Fire spread to neighbouring buildings	OP3.1
Failure of sprinkler system to function as expected	OS1.4, OP1.4
Occupants not being able to recognize fire	OS1.4, OS1.5, OP1.4
Occupants not being able to evacuate the building	OS1.4, OS1.5, OP1.4
Fire Service unable to conduct effective firefighting operation	OS1.2, OS1.3, OP1.2, OP1.3, OP3.1

Based on the technical risks identified, the following analysis for a 5 or 6 storey wood-frame building can be provided:

- **Risk of Ignition:** *Will not likely increase.*
  The risk of ignition will not likely increase provided the gross floor area in a 5 or 6 storey wood-frame building remains the same as the maximum permitted area for a 4 storey wood-frame building under Article 3.2.2.45. The Article derives building area based on dividing the gross floor area of $7200m^2$ by the building height. For example, a 1 storey wood-frame building is permitted a building area of $7200m^2$and a 4 storey wood-frame building is permitted a building area of $1800m^2$. The Code manages the risk of ignition by maintaining the same gross volume in wood-frame constructions. Using $7200m^2$ as the acceptable level of performance, a 5 or 6 storey wood-frame building should be limited to $1440m^2$ and $1200m^2$ in building area respectively, in order to maintain the same level of performance. By maintaining the same gross floor area, and given the same occupancy classification of Group C, the risk of ignition – the probability of ignition and the consequential losses – will not likely increase, as the use and the characteristics of the wood-frame building remains the same.

- **Risk of Fire Spread beyond Point of Origin:** *Will not likely increase.*

  Generally, there are two forms of fire spread in a building: interior and exterior (through unprotected openings). The current BC Building Code addresses fire spread by implementing sprinklers and fire separations. Sprinklers are active fire protection systems which are reliable and effective in controlling the growth and spread of a fire. On the other hand, fire separations are passive; they independently provide a barrier against spread of fire, with or without the operation of sprinklers.

  Given that a 5 or 6 storey wood-frame building will be sprinklered and that the same degree of fire separations will be provided as inherent with Group C occupancies, the risk of interior fire spread will not likely increase. This is because both the active and passive fire protection systems will offer the same level of protection against interior fire spread, independent of the building height. Sprinklers in a 5 or 6 storey wood-frame building will be based on NFPA 13, as NFPA 13R is limited to 4 storeys. As sprinklers are designed on a per floor area basis and NFPA 13 is a more stringent standard than NFPA 13R, sprinklers can be expected to offer a greater level of protection than that offered by NFPA 13R, which is permitted for a 4 storey wood-frame building.

  Similarly, the use of 1h rated fire separations in a 6 storey wood-frame building will offer the same level of performance in resisting fire spread as that of a 4 storey wood-frame and a 6 storey light steel-frame building. The performance of fire separations are measured by the CAN/ULC-S101 standard fire test. The test exposes assemblies to the standard time-temperature curve and assigns an hourly rating based on the passing criteria. The standard test is not predicated on the assembly's material of construction. When the fire test determines a fire resistance rating of 1h for a wood stud wall, a steel stud wall, or a concrete wall, all three types of construction are considered as having the same level of fire resistance of 1h based on the fire test; therefore, when a 1h rated fire separation is used in a 6 storey wood-frame building, the separation is considered to offer the same level of protection as that offered by a 1h rated fire separation in a 4 storey wood-frame or a 6 storey light steel-frame building.

  With respect to exterior fire spread through windows (which is not to be confused with fire spread to neighbouring buildings), the use of combustible exterior cladding as is currently permitted for combustible buildings may lead to greater risk of exterior fire spread. Until this situation is analyzed further, use of noncombustible cladding or the limited types of combustible cladding permitted for noncombustible buildings should be considered for 5 and 6 storey wood-frame buildings.

  Finally, with respect to fire spread within concealed spaces, the mandatory application of the NFPA 13 standard will appropriately manage the risk. There may be an increased risk when sprinklers fail; however, this form of risk is already contemplated by the Building Code and can be further addressed through proper fire blocking.

- **Risk of Fire Spread to Neighbouring Buildings:** *Will not likely increase.*

  The Code assumes fire spread to neighboring buildings by means of radiation heat transfer. In order to manage this risk, the Code places a requirement on the allowable size of unprotected openings and exterior wall construction based on the separation distance between two buildings. In doing so, the Code attempts to control the incident radiation heat flux on the exterior walls of neighbouring buildings to be less than $12.5kW/m^2$, which is the level where wood-based material could undergo piloted ignition. The assumption is that at this radiation level, flying brands could act as the pilot and cause ignition of hot surfaces. Employment of active and passive fire protection systems effectively lower the radiation level, given that radiation heat transfer is highly dependent on the temperature and size of the emitting surface. By sprinklering the fire compartment, the Code assumes that the temperature will be lower, which is reflected in the doubling of unprotected openings allowed by the Code. Use of fire separations will also generally confine the fire to the compartment of origin such that the size and the number of the emitting surfaces will be controlled. The approach of managing the risk of building-to-building exposure is well established in the current Code and is largely based on the results of the series of NRC tests known as the "St. Lawrence Burns".

Assuming that the same exposure protection approach will be taken in a 5 or 6 storey wood-frame building, the risk of fire spread to neighbouring buildings will not likely increase. This is because the size of exposing surfaces via the unprotected openings will be restricted on the same basis as a 4 storey wood-frame or a 6 storey light-steel frame building. In fact, irrespective of the type of construction, all buildings built in accordance with Division B are all subject to the same exposure requirements of Subsection 3.2.3 of Division B. Further, if the exterior cladding of 5 and 6 storey wood-frame buildings are restricted to be noncombustible or to limited types of combustibles as discussed earlier, this will further limit the risk of fire spread on the exterior wall, thereby reducing the risk of a larger exposing face in a 5 or 6 storey wood-frame building. In this regard, the risk of building-to-building exposure for a 5 or 6 storey wood-frame building can be expected to be less than that of a 4 storey wood-frame building.

- **Risk of Failure of Sprinkler System to Control / Suppress Fire:** *Will likely decrease.*
  As discussed, the NFPA 13 standard will be the applicable sprinkler standard for 5 and 6 storey wood-frame buildings of residential occupancy, because NFPA 13R is limited to buildings that are less than 4 storeys in building height. Given sprinklers work on a per floor area basis and are independent of the building height, the risk of sprinklers failing to control a fire in a 5 or 6 storey wood-frame building will not increase relative to a 4 storey wood-frame or a 6 storey light steel-frame building. Given that NFPA 13 is a more stringent standard, the risk will actually decrease relative to a 4 storey wood-frame building as NFPA 13 requires sprinklering of concealed spaces.

- **Risk of Occupants Not Able to Recognize Fire:** *Will not likely increase.*
  Occupant response time to fire cues and decision-making prior to evacuation will not likely increase based on the mandatory requirement of a central fire alarm and sprinkler systems for a 5 or 6 storey wood-frame building. This is because fire detection system alarm system and occupant behavior are all independent of the building height. Therefore, the risk of occupants unable to recognize fire will not likely increase.

- **Risk of Occupants Not Being Able to Evacuate the Building:** *Will not likely increase.*
  The Code's general approach to evacuation in buildings is based on controlling occupant load, providing sufficient means of egress, and managing accessibility, availability and integrity of exit systems. Assuming the gross floor area of $7200m^2$ is maintained in a 5 or 6 storey wood-frame building, the occupant load will not change. Travel time to an exit within a storey will likely decrease due to smaller building area and less queuing at exits as a result of fewer occupants per floor. Travel time within exit stairs would increase due to 2 additional storeys; however, as exits will need to be separated by 1h fire rated construction and travel time within exits will be the same as that of a 6 storey light steel-frame, in our opinion the exit stairs will provide the same level of fire safety. The 1h exit fire separation would offer the same level of protection against fire, irrespective of the material of construction as aforementioned, which will afford an acceptable time for evacuation and for firefighting use.

- **Risk of Fire Service Unable to Conduct Effective Operation:** *Will not likely increase.*
In comparison to a sprinklered 4 storey wood-frame or a 6 storey light steel-frame building, the risk of fire service unable to conduct effective operations will not likely increase for a 5 or 6 storey wood-frame building, provided the building will not be a high building. In sprinklered mid-rise buildings, firefighting is generally conducted in the interior of the building, and the sprinkler system provides adequate relief to firefighting in comparison to unsprinklered buildings. As well, the effects of stack action, which is typically more prevalent in high buildings, will not be significant in mid-rise wood-frame buildings.

Traditionally, unsprinklered 3 storey wood-frame constructions relied on exterior firefighting operations. With the advent of buildings protected with monitored and supervised sprinkler systems and related firefighting practices, the Code have shifted to reliance on the sprinkler systems and interior firefighting access. This is reflected in several recent Code changes, including:

- Eliminating the requirement for fire rated roofs in sprinklered buildings;
- Eliminating the requirement for access openings for firefighting in sprinklered buildings;
- Removal of the requirement for larger buildings to face streets; and,
- Introduction of 4 storey 1h construction in the BC Building Code 1992 and the subsequent removal of the 9m height limit in the BC Building Code 1998.

These changes all reflect the fact that the Code does not anticipate exterior firefighting for sprinklered wood-frame buildings and recognizes the reliability and effectiveness of automatic sprinkler systems. Therefore, the primary change from 4 to 6 storeys is access up an additional 2 storeys of interior stairs. However, this is in part offset by the reduced floor area from a maximum $1800m^2$ for 4 storeys to $1200m^2$ for 6 storeys, as well as the consideration that the operation would be the same as in a 6 storey light steel-frame building with a 1h fire rated construction. Further, 4 storey wood-frame buildings typically have unsprinklered attics. Extension to 6 storeys will require attics and balconies be sprinklered, as is already required by NFPA 13. Accordingly, there is no foreseeable risk increase with respect to the effectiveness of firefighting, particularly considering that a 5 or 6 storey wood-frame building will be sprinklered to NFPA 13.

There is a risk of fire spread due to combustible exterior cladding for 5 and 6 storey buildings and balcony fires; however, as discussed, this can be managed by imposing measures to limit flame spread on exterior cladding or use of automatic sprinklers in balconies.

As the building is over 3 storeys, standpipes will be inherently required by Code.

For rural areas of BC where the region may have limited firefighting capabilities, the BC Building Code Appendix Commentary already notes that this can be addressed through either requiring mandatory sprinklers or imposing restrictions through Municipal Zoning By-laws. With respect to the sprinkler option, where the region lacks the capability of properly supporting the sprinkler system, additional measures such as emergency power generator, fire pump, and on-site water supply can be used to enhance the reliability of sprinkler system, in conjunction with enforcement of proper maintenance of sprinkler system.

Based on the foregoing discussion, a 5 or 6 storey wood-frame building of residential occupancy following the building area restriction formula already employed in Article 3.2.2.45 for up to 4 storeys will appropriately manage the risks which are recognized by the Code through the objectives.

It is noted that fire statistics in BC obtained through BSPB have shown that sprinklers are effective in managing all risk areas addressed by the Code, except the probability of ignition occurring. The statistics suggest that when buildings are sprinklered, irrespective of the type of construction and the building height, the number of fire-related fatalities and injuries in buildings are significantly reduced. The fire statistics would lend us to believe that a sprinklered 5 or 6 storey wood-frame building would not expose occupants to a greater risk than in that of a 4 storey wood-frame or a 6 storey light-steel frame building.

Process Risks

Process risk is the risk relating to the use of the Building Code. For this project, it specifically relates to the risks that arise out of constructing a 5 or 6 storey wood-frame building. It is important to recognize that the current Building Code objectives do *not* address process risks. Process risk was specifically asked to be identified, which is aimed at assisting the BC Government in managing the implementation aspects of the project. Identifying process risk is therefore less straightforward than that of technical risk. Our approach has been to consult stakeholders such as AHJs in BC, the Homeowner's Protection Office, warranty providers, researchers at FPInnovations Forintek, as well as process the comments received during the Technical Advisory Group meetings held by BSPB. Out of this process, we have identified the following process risks:

- **Qualification of Design Professionals**
  A major concern raised by many parties is the need for qualified professionals. Currently, the Letters of Assurance require a professional qualified in structural engineering, but do not specifically require a professional qualified in fire safety. Education in Building Code requirements is provided to Architects but is limited. Significant additional Building Code education is provided through the Certified Professional (CP) program, but it is not specific to wood-frame construction, nor does the program include fundamental fire engineering education such as fire dynamics, transport phenomenon and combustion.

  Further, the use of a CP is currently optional and limited to the Cities of Vancouver and Surrey. The increased complexity of 6 storey buildings, combined with the impact of shrinkage on fire separations, fire blocking and fire stopping, and the increased reliance on firewalls may necessitate the involvement for a professional fire engineer. In this respect, we have identified two potential solutions to address qualifications of professionals. One solution is to consider the mandatory involvement of a fire engineer in a 5 or 6 storey wood-frame project. The second solution is to consider the development of a "best practices guide" for 5 and 6 storey wood-frame buildings, which would set forth the standard of care required of professionals in 5 and 6 storey wood-frame buildings. Until an appropriate solution is developed to address this process risk, design professionals are required by APEGBC and AIBC guidelines to diligently ensure that the standard of care required by the public of BC is delivered.

- **Qualification of Design Reviewer / AHJ**
  With 5 and 6 storey wood-frame buildings in the Code, significantly more complex buildings may be proposed as alternative solutions. This may include proposals for mixed occupancies, use of other types of combustible materials (given that "wood-frame" is only one form of combustible construction), use of mixed combustible and noncombustible materials, creation of interconnected

floor spaces and proposals for increase in building height. Development of these alternative solutions will require a thorough understanding of the fire science and fire engineering principles. As compliance with the objective-based Code can be achieved through either the acceptable solutions or the alternative solutions, it would be necessary for design reviewers or AHJs to have similar qualifications as that of the design professionals. Although there is no regulatory framework currently in place, certain municipalities have addressed review of designs through peer-review or employment of a qualified fire engineer to act as the AHJ. Both of these approaches are considered as appropriate solutions to address the process risk.

- **Readiness of Warranty Providers**
  Interviews with three major warranty providers in BC indicate that generally, insurance for 5 or 6 storey wood-frame buildings of residential occupancy will be highly dependent on the competence and qualification of contractors. The warranty providers indicate that with respect to fire safety, they normally rely on the design professionals, and that they would insure buildings initially based on contractors who have demonstrated good records with 4 storey wood-frame buildings.

- **Readiness and Qualification of Contractors / Trades**
  Construction of a 5 or 6 storey wood-frame building is not significantly different from a 4 storey wood-frame building; however, there is a significant concern anticipated with some contractors' ability to construct 4 storey wood-frame buildings and the same concern extends to 6 storey wood-frame buildings. The increase to 6 storeys increases the need to appropriately follow the correct design; therefore, the risk of unqualified contractors may increase. There is currently no process for qualification of contractors or the trades related to framing gypsum wallboard fire separation and fire blocking. Training for fire stopping is available but is of little use without proper qualifications of those responsible for framing, fire blocking and fire separations. Some of the possible solutions to address this risk include greater field review by design professionals and AHJs, 3rd party independent inspection, and more education and training of trades.

- **Reliability of Membrane-based Fire Separation**
  Reliability of fire separation and fire protection of structural members is not an objective of the Building Code. As discussed under the technical risks section of this report, the fire endurance test (CAN/ULC-S101) is a performance test that is not predicated on the assembly's material of construction. Notwithstanding this, the Code has traditionally addressed reliability of construction in certain critical areas of a building indirectly. For example, the Code requires a 1.5h rated fire separation around parking garages and has traditionally required concrete or masonry construction for firewalls and the horizontal fire separation of Division B, Article 3.2.1.2. With respect to wood-frame construction, there is a general concern regarding the reliability of membrane-based fire separations as when the wood-frame is exposed to fire, the frame, being combustible, would directly fuel a fire. Laboratory tests clearly show that a single layer of gypsum wallboard on wood joists can achieve a 1h FRR; however, there is little validation of actual constructed separations in the field. Recent NRC testing has shown that single layer designs are susceptible to improper joint construction, improper attachment of the gypsum wallboard and improper installation. Further, tests in Japan, Europe and New Zealand, including the recent full scale 6 storey timber-frame project in the UK (T2000), have indicated the need for increasing durability of GWB-based fire protection. In view of this, it is considered that reliability of fire separations needs to be addressed. Some of the potential solutions include better craftsmanship of GWB installation, greater reviews during construction, and mandatory use of two layer wall assembly systems.

The foregoing section has presented the process risks. The work should not be considered as exhaustive or complete. We understand the Government of BC has been providing opportunities for public consultation during which other process risks may be identified. Some of the process risks may be addressed through Code changes, while others may be best tackled by best practices guides and greater training. It is the Government of BC's responsibility to ensure that the process risks are appropriately managed.

3.0 FUTURE WORK

The foregoing report has provided GHL's opinion on the technical and process risks with respect to the 5 and 6 storey wood-frame project. In our work and through participating in the Technical Advisory Group meetings, we also recommend the following future work for consideration:

- **Building Height and Area**
  The foregoing analysis is based on the existing floor area formula of the Code in Article 3.2.2.45. The formula would result in a building area of $1440 m^2$ or $1200 m^2$ for a 5 or 6 storey wood-frame building, respectively. Our review of previous editions of the Building Code and related Code change documents indicates that there is limited technical basis for the area and height limits that are currently prescribed in all combustible constructions of Subsection 3.2.2. It would be appropriate as an additional work to re-examine the height and area limits for combustible construction for all occupancies for greater allowance.

- **Construction Fire Safety**
  As part of this work, GHL has received input from stakeholders of the need to address construction fire safety. In our opinion, provided the gross floor area of $7200 m^2$ is maintained, we do not see an increased risk of construction fire, given that the same amount of combustibles would be allowed; however, if greater building area were to be explored, then a complementary study on the issue of construction fire safety would be necessary as the combustible load will be effectively increased during the construction stage.

- **Reliability of Sprinklers**
  A study into the reliability of sprinklers and their application in the Building Code (by acceptable or alternative solutions) would also be beneficial. Currently, a number of Code requirements are predicated upon the building being sprinklered. For example, the allowable building area is generally doubled when a building is sprinklered; however, there is no clear information as to the extent designers can rely on sprinklers, whether the Code requirements already appropriately accounts for the risk of sprinkler failure or even if doubling the building area is the appropriate figure. A study of this nature would benefit the formulation of alternative solutions and allow designers and AHJs alike to understand when the benefits of sprinklers can be considered.

- **Aging Population**
  We have received comments concerning assisted living type occupancies which are now classified as Group C. There is a general concern of whether this group of occupants would be exposed to greater risk in 5 or 6 storey wood-frame buildings. Our analysis indicates that in a properly constructed 5 or 6 storey wood-frame building, the risk would be the same as a 6 storey light steel-frame building, or less than an unsprinklered 3 storey wood-frame building. Notwithstanding this, we do agree that the current Code, as a whole, does not address the aging population, which is applicable in almost all occupancies (except probably Group F-2 and F-1 occupancies); ie., the issue of slower evacuation time is as relevant in a 6 storey wood-frame as it is in a 6 storey steel-frame or a 60 storey concrete high rise. A study on this issue will be valuable to the public of BC as the province sees an aging population.

4.0 CONCLUSION

This technical report has been prepared by GHL for the Ministry of Housing and Social Development to identify and provide our opinion on the technical and process risks relative to fire safety aspect of the Mid-Rise Wood-Frame Residential Construction project.

Technical risks are identified by the Building Code objectives. GHL's analysis has focused strictly on the risk areas addressed by the Code objectives. We have taken a qualitative approach to analyze the risks by comparing a 5 or 6 storey wood-frame building of residential occupancy to that of a 4 storey wood-frame or a 6 storey light steel-frame building. In general, our finding is that provided the same gross floor area of $7200m^2$ is maintained, ie., $1440m^2$ building area for a 5 storey building and $1200m^2$ for a 6 storey building, the risks will not likely increase due to the use of sprinklers and fire separations, which are well-established requirements in the current Code. We did find that in order to limit exterior fire spread, noncombustible or limited types of combustibles exterior cladding should be considered. Further, in order to address firefighting, the building should not be a high building.

We have also addressed process risks which are not addressed by the Building Code. At the request of BSPB, GHL has identified the process risks outlined in this report through consultation with key stakeholders as well as processing the input received during the Technical Advisory Group meetings held by BSPB. In summary, the process risks generally relate to the process of constructing a 5 or 6 storey wood-frame building in accordance with the Code. The risks can be managed through either having mandatory regulations in the Building Code or through development of best practices guides and education programs to enhance the understanding of the standard level of care required of professionals and trades in 5 and 6 storey wood-frame buildings.

Areas of future work are recommended.

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* Limitation of Liability *

This technical report addresses only specific Building Code issues under the GHL/Client agreement for this project and shall in no way be construed as exhaustive or complete. This technical report is issued only to the Authority Having Jurisdiction, the Client, Prime Consultants and Fire Suppression Designer to this project and shall not be relied upon (without prior written authorization from GHL) by any other party.

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MULTI-LEVEL WOOD-FRAMED STRUCTURES: REQUIREMENTS FOR BUILDING BEYOND FOUR STOREYS

A SCOPING REVIEW

DATE: JUNE 18, 2008

REV JUNE 30, 3008

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INTRODUCTION

Over the past decade, several major urban centres within the western United States have loosened restrictions limiting the building of wood-frame structures to only four-storeys. The push to amend legislation to allow the building of five- or six-storey wood-frame structures reflects the desire of city planners to increase urban density and provide citizens with additional affordable housing options. As world steel costs continue to rise, developers have increasingly chosen wood over steel in the framing of multi-story buildings in jurisdictions where this type of construction is allowed. Organizations like the Canadian Wood Council, the Western Wood Products Association in the United States, and the Trees and Timber Institute of the National Research Council in Italy all advocate the increased use of wood frame for buildings of five storeys and beyond.

Legislation that limits the building of wood-frame structures to only four storeys is related to the concern that structures over four storeys represent a potential fire hazard. According to Kevin Cheung, a recognized expert in the field of multi-storey wood-frame construction, “building codes have height and area limitations on wood construction due to fire safety considerations” (Cheung, 2000, p.4). Many of the regulations that limit wood-framed structures to only four storeys have their origin in great urban fires such as the Great Fire of London in 1666 and the Boston Fire in 1872. In light of numerous fire safety innovations delivered through modern technology there is little reason to continue limiting the height of wood-framed buildings to four storeys (Smith and Frangi, 2008). In jurisdictions where legislation has been amended to allow for height increases, the assurance that fire safety would not be compromised has been central to these projects receiving city council approval.

Several jurisdictions that have amended local legislation to allow five- or six-storey wood-frame structures have stipulated that the ground floor be comprised of non-combustible material. These “four-over-one” and “five-over-one” structures are built to construction specifications that require the first floor be made of steel and/or concrete. These measures help ensure a building’s structural stability in the event of a fire as well as add a degree of fire protection for parking garages or retail space located on the first floor. In San Francisco, a common building type for these projects is four-storeys of wood-frame built over a concrete ground floor of parking and retail space (Spur, 2007, November).

Other structural considerations related to fire safety issues that have been incorporated into the design of “four-over-one” and “five-over-one” buildings include the requirement that the first wood-frame storey provide 2 hours of fire rated construction. Jurisdictions have also stipulated that buildings must contain exit enclosures that are protected by 2-hour fire resistive construction, pressurized exit enclosures and elevator shafts, fire walls, automatic fire-sprinklers, and stand-by power sources to ensure continuous operation of fire protection systems. These modifications are designed to maximize escape time in case of fire, particularly for occupants located on the top two floors.

Aside from fire safety considerations, multi-floor wood-frame construction also faces challenges related to wood shrinkage, a process in which the moisture content evaporates, which causes changes to the physical properties of the wood. According to Kevin Cheung "the cumulative effects of multi-storey shrinkage can cause large expanses of interior and exterior drywall, paneling and siding to buckle" (Cheung, 2000, p.3). Within this Review, documents listed in the "Works Cited" section provide detailed explanations on how builders can overcome wood shrinkage challenges.

Seismic considerations also pose a challenge for multi-storey wood-frame construction builders; however, experimentation within this field has proven that multi-storey wood-framed structures can withstand the most severe seismic event through specialized design and material usage.(rev 06.30.08) In 2007, the Italian SOFIE project successfully tested a seven-storey wood-framed structure on the world's largest shaking table at Japan's National Institute for Earth Science and Disaster Prevention. It must be noted, however, that this wood-framed structure used specialized wood products such as engineered laminated material and is not directly relevant to North American typical wood-frame construction. (rev 06.30.08)

In the United States at the University of Buffalo, the National Science Foundation has sponsored the multi-university NEESWood project that "seeks to take on the challenge of developing a seismic design philosophy that will provide the necessary mechanisms to safely increase the height of wood-frame structures in active seismic zones" (NEESWood, 2007). The NEESWood project will culminate in early 2009 when a six-storey wood-framed structure will be shipped to Miki City, Japan to undergo tests similar to those conducted during the SOFIE project.

CONTEXT AND SCOPE

This Scoping Review will provide analysis of the issues surrounding multi-storey wood-framed construction and an inventory of documents related to this issue. The purpose of this Scoping Review is to enlarge the readers' understanding of the regulatory solutions that have facilitated the construction of five- and six-storey wood-frame buildings. The Review will also strive to enhance the reader's knowledge of the various structural, seismic, and fire safety related challenges that are being addressed by those involved in the building of wood-framed structures over four storeys. This Review will not attempt to provide a detailed analysis of engineering technologies that support these projects, but will point to locations where information on these technologies can be located.

DEFINITIONS

SINGLE CONSTRUCTION

Within the context of legislation that pertains to the construction of multi-storey wood-framed buildings, the term "single construction" refers to a wood-framed building, up to a maximum of five-storeys, with Type V-1 Hour construction. Type V-1 Hour construction refers to any home built with a "Protected Wood Frame," which has no visible exposed wood, and provides 1 hour of fire resistive protection. "Single construction" is all wood-framed (Portland, Oregon. 2004).

MIXED CONSTRUCTION

Within the context of Oregon legislation that pertains to the construction of multi-storey wood-framed buildings, the term "Mixed Construction" refers to a type of wood-framed building of six-storeys, where the basement or first floor is constructed of Type I-Fire Resistive Non-Combustible materials that provide up to 3 hours of fire resistive protection in combination with the top five-storeys that meet the design specifications of TypeV-1 Hour construction. "Mixed Construction" is essentially a wood-frame built upon one storey of non-combustible material (Portland, Oregon, 2004).

DISCUSSION

1. LITERATURE REVIEW

1.1 Considerations of Multi-Storey Wood-Frame Construction

According to Kevin Cheung, an expert in the field of multi-storey wood-framed construction and an advocate for increasing this type of construction, "three- or five-storey wood-framed buildings offer economical housing through fast construction speed and low material costs" (Cheung, 2000, p.1). His essay *Multi-Story Wood-Frame Construction* (2000) discusses the structural advantages of wood-frame construction as well as wood shrinkage, fire safety, and sound transmission issues related to this area. Cheung also discusses three multi-storey wood-frame construction projects in the United States.

1.1.2 Seismic, Structural, Fire Safety and Sound Transmission Considerations

Cheung notes that wood is a timeless building material known for its structural capabilities. Wood assembly offers a high strength-to-weight ratio, resulting in a low inertia force during a **seismic event.** The large number of walls used in wood-framed construction reduces the load shared by each wall. These structural walls transfer the lateral load induced at the time of an earthquake. During recent earthquakes, damage to most wood-frame structures occurred to homes built prior to modern seismic code requirements. These buildings were inadequately braced or slid off foundations because they lacked hold-down bolts (Cheung, 2000, p.2).

Wood shrinkage must be considered for wood-frame structures over three-storeys. The use of dry lumber (below 19% moisture content) will minimize wood shrinkage problems like cracking to the finish and distress caused to plumbing systems. The effects of multi-storey shrinkage can cause interior and exterior drywall, paneling, and siding to buckle. Areas such as stairwells, shafts, and vaulted ceilings are especially vulnerable to cracking due to wood shrinkage. Cheung discusses a number of building methods that can help minimize wood shrinkage effects (Cheung, 2000, p.3). New more sophisticated engineered wood products are often used to increase performance of wood with respect to shrinkage and seismic response. The issue of shrinkage is particularly critical in coastal BC where lumber is rarely dry during the construction period and shrinkage issues are exacerbated due to the climate. This is an issue that will require expertise and knowledge on the part of the designers, contractors, trades and building officials. (rev 06.30.08)

Fire safety issues must also be addressed when increasing building height and area limitations. One-hour fire-resistive construction is usually the minimum, with higher fire endurance ratings being required for stairways and exit hallways. Fire-stopping techniques are often used to prevent flames from moving to other areas of a building. Draft-stopping is also used to prevent the movement of air, smoke, gas and flames (Cheung, 2000, p.4).

Sound transmission is an important design consideration if a structure is a multiple family residential building. Lightweight gypsum concrete and other sealers are often used to reduce sound transmission in wood-frame construction. Lightweight concrete, poured on the floor after framing has been completed, is often used to improve sound reduction (Cheung, 2000, p.4).

1.1.3 Advantages of Wood-Framed Construction

Wood-framed houses have a **low energy usage**, when compared to concrete built structures. Wood is easy to insulate to high standards, whereas concrete and steel construction must overcome challenges related to thermal bridging and moisture condensation on cold surfaces. Light metal framing reduces thermal resistance by nearly 50%, which results in increased energy use. Because wood-framed construction is easily adaptable to any energy code, wood-framed buildings help lower energy bills (CWC, 2002, p.4).

Wood-framed buildings **require less energy and emit less carbon** when compared to concrete buildings because (European Commission, 2006):

- Production of materials for wood-frame buildings uses less primary energy than for concrete-frame buildings.
- The difference in life cycle emissions between wood and concrete framed buildings ranged from 30 to 130 kg of carbon per square meter of floor area.
- From a lifecycle perspective, the net change in carbon stocks (tree biomass and wood building stocks) is insignificant when using wood-based building materials from sustainably-managed forests.

Wood-framed buildings **cost less to build** than concrete and steel buildings resulting in greater urban density and, presumably, more affordable housing options. However, the use of engineered wood products, as compared to dimensional lumber, to mitigate structural, seismic and shrinkage issues will affect the overall cost of construction. A cost benefit analysis should be developed to understand the true differences in cost. (rev 06.30.08)

1.1.4 Examples of Multi-Storey Wood–Frame Buildings

- The 165,000 square–foot Copperfield Hill retirement community building in Minneapolis, Minnesota. Wood frame was chosen for this project based on cost when compared to a steel-concrete frame. The ease of wood construction **shortened construction timelines** by allowing the project to be framed in just over 5 months (Cheung, 2000, p.5).
- The Delancey Street Foundation Triangle Complex in San Francisco is also discussed. This 325,000 square foot, seven building complex has four residential buildings over one-storey of post-tensioned concrete parking and retail space. The residential structures are three-storey wood-frame over one floor built of non-combustible materials (Cheung, 2000, p.6).

- The Gatesworth building in St. Louis, Missouri is a four-storey wood-frame building with one five-storey wing. It contains 280,000 square feet of residential space plus 65,800 square feet of parking space under the building. Wood-frame was chosen for this project because of the developer's familiarity with wood frame construction. Framing was completed in only 15 months (Cheung, 2000, p.7).
- Denny Park Apartments in Seattle, Washington is a 55,000 square foot, six-storey, mixed-use building. The top five storeys of wood-framed construction contains various studio, 1 bedroom, 2 bedroom, and 3 bedroom apartments. The bottom two concrete floors contain retail space and a basement parking garage (Design Advisor Website).

Denny Park Apartments, Seattle, Washington (Design Advisor Website).

1.2. Engineering and Technological Solutions

1.2.1. "De Wiers" House – The Netherlands

"De Wiers" house, the highest multi-storey timber building in the Netherlands, is four wood-framed storeys over one floor of timber and masonry. The design and construction of "De Wiers" house has encouraged acceptance of multi-storey wood-framed building because the project addressed challenges related to floor vibrations, fire resistance, and acoustic transmission (Jorissen & Leijtin, 2008).

The structure is comprised of a five-floor 2D portal frame in four bays and is designed to allow the floors maximum flexibility. The fire resistance challenge was solved by increasing the dimension of the cross-sections. Timber floors were topped with floating concrete to increase fire resistance and limit acoustic transmission (Jorissen & Leijtin, 2008).

Huis de Wiers, Netherlands (Jorissen & Leijtin, 2008).

1.2.2. University of Canterbury – New Zealand

Presently, the University of Canterbury is developing a new system for multi-storey timber buildings to be used when building up to 10 storeys or more. Buildings designed to this system will have (Buchanan et al, 2008, May):

- Heavy timber beams, columns or walls;
- Large structural members prefabricated off-site;
- Main timber structure of glulam (glued-laminated timber) or laminated veneer lumber members;
- Post-tensioned connections for easy building and high-seismic resistance;
- Removable partitions and cladding; and
- Composite T-beam floors with concrete topping on timber joists.

The performance requirements for buildings designed to this system include (Buchanan et al, 2008, May):

- Wide open spaces, with maximum flexibility of use;
- Residential, educational or commercial use;
- Safety in fire, earthquakes or extreme weather events;
- Excellent acoustic performance;
- Excellent thermal behaviour;

- Durability for hundreds of years;
- Low levels of life-cycles energy use; and
- Low CO_2 emissions during construction, long-term use, and demolition.

1.2.3. Wood-Frame Construction Solutions – The United States

The essay *Multi-Story Wood Frame Construction in the United States* (2003) provides a technical analysis of several projects within the US that have pushed building code limits and the limits of wood as building material. The essay covers the technical aspects of multi-storey wood-framed construction and provides several examples of how builders have met the challenges associated with building beyond four-storeys. This essay provides technical information far beyond the scope of this review. A complete copy of this document is available at the web address provided below.

Web link: http://www.timberdesign.org.nz/files/Multi-Storey%20Wood%20Frame%20Construction%20in%20the%20US.pdf

1.2.4. Italian High-Tech Wood-Framed Building Passes Seismic Test

On October 23, 2007, a seven-storey wooden house passed all seismic tests after being exposed to a simulation of the earthquake that destroyed Kobe, Japan in 1995 (Carrer, 2007). It must be noted, however, that the construction methodology and materials was unique and therefore the results of this test is not directly transferable to the typical North American wood-framed building. (rev 06.30.08) The test occurred on the largest “shaking table” in the world, located in Miki, Japan, at Japan’s National Institute for Earth Science and Disaster Prevention. The SOFIE project (named after the research project "Sistema Costruttivo Fiemme") is a collaboration between the Trees and Timber Institute (IVALSA) of the National Research Council in Italy and the Autonomous Province of Torino, and was undertaken to demonstrate “the absolute reliability and safety…of wood as a construction material: a valid and cost-effective alternative to traditional building methods” (Progettosofie, 2007).

The seismic test in Miki was the final component of the SOFIE project, which examined the performance and capabilities of the X-Lam (Cross-Laminated Timber) construction system. The X-Lam technique originated approximately ten years ago in Germany but has been recently perfected in Italy. The X-Lam system is comprised of massive cross-laminated wooden panels that range from 5 to 30 centimetres in thickness. Panels, door openings, windows, and staircases are cut to size then fastened with steel angles, ringed shank nails, and self-drilling screws (Progettosofie, 2007).

X-Lam (Cross-Laminated Timber) Construction System (Holz Build)

The specifications of the seven-storey house tested in Miki were 15m by 7.7m floor plan area and 24m total height with one pitched roof. The building walls were constructed of X-Lam panels with a thickness of 142mm at the first two floors, 125m on the third and fourth floor and 85 mm at the last three floors. Several inner walls, with a same thickness as the outer walls, served as load carrying walls. The walls were connected with self-drilling screws. The floors were made of X-Lam panels with a thickness of 142mm that were connected to the walls by screws and steel brackets. The total volume of wood for the panels was around 250m^3 (Progettosofie, 2007).

Seven-Storey, X-Lam System Seismic Test (Progettosofie, 2007)

1.3 Scientific Literature – Multi-Storey Wood-Frame Construction

Web link:
http://www.ingentaconnect.com/content/iabse/sei/2008/00000018/00000002;jsessionid=7usee34nfu8k7.alice

This section of the Review provides a list of abstracts that have been excerpted verbatim from their original source and can be located at the web link address listed above. The May 2008 edition of *Structural Engineering International* provides several other articles pertaining to multi-storey wood-frame construction; however, those listed below examine the issues most prevalent to this Review.

1.3.1 Urban Timber Houses in Vienna

Author: Martin Teibinger
Cost: $25US

Project "Mühlweg" of more than 250 flats in Vienna with four-and five-storey timber houses is described in this paper. In 2001, the building code of Vienna was modified to make way for the establishment of multi-storey timber houses with up to five storeys, provided that the supporting elements for the ground floor are made of mineral materials. In regard to multi-storey apartment building in Vienna these building methods were innovative. The city of Vienna has initiated a new focal point in public housing by promoting timber construction through advertising a competition amongst property developers. These timber constructions constitute something of an innovation in the area of multi-storey housing in Vienna. The advantages of timber buildings clarify why timber construction will play a major role in the future: High-grade prefabrication along with shorter construction periods, minor construction material moisture and ecological aspects (Structural Engineering International, 2008 May).

1.3.2 Case Studies of Multi-Storey Wood-Frame Construction in USA

Author: Cheung, Kevin C.K.

Shortage of affordable housing is a problem shared by many major cities in the USA. Three- to five-storey wood-frame buildings offer economical housing through low construction cost and high speed of construction.
In the designing of multi-storey wood-frame buildings, fire-safety and structural considerations are required by building codes. In addition, shrinkage and sound transmission do require special attention.
Most Americans live in the suburbs in low-rise wood-frame constructions, including single-family detached houses and one- to three-storey apartments and condos. This has resulted in what is known as suburban sprawl—widely spread

population, increasing the cost to the local government in providing streets, water, and sewer services. Planning for the shifting demographics and rising land cost, US cities are turning to densifying housing development of in-fill projects in the city and new development projects in suburban town centres.

1.3.3 Building Tall with Timber: A Paean to Wood Construction

Author: Randolph Langenbach
Cost: $25US

It may seem strange at first to propose that timber be used for the structural system of mid-rise buildings. Steel and concrete have held that position so long that the question of wood as an alternative for large-scale multi-storey construction would strike many people as archaic and impractical, but until the modern age, this was the case. The following essay highlights some interesting examples in history, concluding with the 17 blimp hangers constructed in the USA during World War II when steel was in short supply. Each of these structures was a third of a kilometre in length and equivalent in height to a 17 storey building, containing a single, column-free room (Structural Engineering International, 2008 May).

1.3.4 Overview of Design Issues for Tall Timber Buildings

Authors: Ian Smith and Andrea Frangi
Cost: $25US

Timber buildings, like any others, exhibit exemplary performance when materials are used appropriately, when structural forms and construction details address overload and serviceability requirements, and when geometry and interior layouts address fire safety. Many building codes restrict timber buildings to four and six storeys, reflecting societal consciousness of effects of conflagrations like the Great Fire of London in 1666. However, the regulatory landscape is changing to recognize contemporary capabilities to detect, suppress and contain fires within buildings. This is freeing architects and engineers to fully exploit structural capabilities of timber as a construction material. On the basis of the notion that tall modern timber buildings means those of approximately 10 storeys to a maximum of about 20 storeys, this paper is a commentary on the main structural engineering issues and how to address them systemically (Structural Engineering International, 2008 May).

1.3.5 Fire Design Concepts for Tall Timber Buildings

Authors: Andrea Frangi; Mario Fontana and Markus Knobloch
Cost: $25US

Based on the current knowledge in the area of fire design of timber structures this paper presents a generic fire safety concept for tall timber buildings. The first part of the paper gives an overview of fire action and fire safety concepts and presents the main differences between medium-rise and tall buildings with regard to fire safety. The analysis enables the formulation of a generic fire safety concept for tall timber buildings. In the second part of the paper some experimental results on the fire performance of timber structures under natural fire conditions relevant for tall timber buildings are presented (Structural Engineering International, 2008 May).

1.3.6 New Technologies for Construction of Medium-Rise Buildings in Seismic Regions: The XLAM Case

Author: Ceccotti, Ario
Cost: $25US

This paper reports on the outcomes of an experimental test performed on a full-scale building constructed using innovative technology. The experimental results are compared with the outcomes of a numerical analysis with the aim to derive the behaviour factor q used in a simplified elastic design of the building under seismic actions (Structural Engineering International, 2008 May).

1.3.7 Multi-Storey Pre-stressed Timber Buildings in New Zealand

Authors: Andy Buchanan; Bruce Deam; Massimo Fragiacomo; Stefano Pampanin and Alessandro Palermo
Cost: $25US

This paper describes recent research and development of a new system for multi-storey prestressed timber buildings in New Zealand. The new system gives opportunities for much greater use of timber and engineered wood products in large buildings, using innovative technologies for creating high-quality buildings with large open spaces, excellent living and working environments, and resistance to hazards such as earthquakes, fires and extreme weather events (Structural Engineering International, 2008 May).

1.3.8 Performance-Based Seismic Design of Six-Storey Wood-frame Structures

Authors: Weichiang Pang and David Rosowsky
Cost: $25US

This paper presents a performance-based seismic design of a six-storey light-frame wood building using a new direct displacement design (DDD) procedure specifically developed for mid-rise wood buildings. The proposed displacement-based design procedure uses normalized modal analysis and equivalent linearization techniques, along with segmented shearwall concepts, and allows engineers to select shearwalls from a database of backbone curves. The multi-storey direct displacement-based procedure is a promising design tool for performance-based seismic design of mid-rise wood buildings because it allows consideration of multiple performance objectives and does not require nonlinear time-history analysis of the complete structure. The proposed procedure further does not require the engineer to provide an estimate of equivalent damping. The proposed procedure is illustrated on a six-storey building and is validated using nonlinear time-history analysis results (Structural Engineering International, 2008 May).

1.3.9 Performance and Drift Levels of Tall Timber Frame Buildings under Seismic and Wind Loads

Authors: Andreas Heiduschke; Bo Kasal and Peer Haller
Cost: $25US

This paper discusses the potential for use of multi-storey timber frames when subjected to earthquake and wind loadings. With the advent of new technologies and materials, such as laminating and composite-fibre reinforcement, the performance of tall spatial timber frames can be significantly enhanced. Two issues are of concern when designing tall timber frames: flexibility that translates into relatively large drifts and non-linearity that represents uncertainty in estimating fundamental periods. This article focuses on the potentials and limitations in designing tall timber frames from serviceability and safety points of view.

As part of the permit application, design considerations include, but are not limited, to the splitting of wood members from shear wall nailing; differential shrinkage of wood, steel and concrete members; differential shrinkage of load bearing walls with and without wood panels; axial and flexural capacity of lower floor studs; and compression of lower floor wood plates (Structural Engineering International, 2008 May).

2. Amending Building and Fire Codes

This section of the review will summarize the city council proceedings of three jurisdictions where construction of wood-frame buildings beyond four-storeys has received approval. Each jurisdiction has placed similar stipulations on increasing building height; however, there are certain differences within each jurisdiction.

Restrictions on building height and occupancy type in multi-storey wood-frame structures are based on issues of fire safety. Issues such as escape time and the ability of fire fighters to access the building in the event of a fire are central to these concerns. These jurisdictions had the opportunity of crafting requirements that are in tune with the building inspection practices and fire fighting capabilities of their particular communities. (rev 06.30.08)

Due to similarities found in many documents pertaining to this issue, only three summaries have been included in this Scoping Review. The three examples provided were chosen because each originated from within a different US State; the first from Washington, the second from Idaho, and the third from Oregon. Additional web links to documents from other jurisdictions, where wood-frame construction has moved beyond four-storeys, are provided after the three examples.

The key risks addressed by the following communities were as follows

- Fire safety risks were addressed by:
    - sprinkler systems, monitored fire protection system, emergency power, pressurized stairwells; and
    - maximum allowable building height.
- Shrinkage and compression risks were addressed by:
    - structural observation.
- Noise transmission and seismic risks were not addressed beyond the current code requirements.

2.1 Bellevue, Washington-City Council Meeting

Building Code Amendment Proceeding Supporting the Allowance of Five-Storey Framed Buildings

The following section of this Review has been included for the purpose of informing the reader how a discussion surrounding the amendment of the building code to allow five-storey wood-framed structures has proceeded in the past.

Bellevue Building Official Division Director Gregg Schrader has stated that previous limits placed on wood-framed construction in Bellevue likely had to do with theoretical limits of wood-framed design at the time the code first addressed the issue. Mr. Schrader has also stated he would be pleased to answer any further questions related to this subject. He can be reached by phone at 425-452-6451, or via e-mail at gschrader@bellevuewa.gov (Schrader, 2008).

On July 16, 2001, Bellevue, Washington City Council met to discuss amending the Building Code to allow five-storey wood framed buildings, with additional fire and life safety features incorporated into their construction. The Planning and Community Development Director stated that this initiative evolved from the City of Bellevue's objectives of:

1) Encouraging the availability of more, and particularly affordable, housing,
2) Maintaining the ability to compete with cities in the area that now allow five-storey wood framed construction, and
3) Maintaining and enhancing fire and life safety requirements for wood framed structures.

Bellevue's building codes are based on those adopted by the International Conference of Building Officials, the National Fire Protection Association, and the Washington State Building Council. At the time of this discussion, the 1997 Uniform Building Code specified the following for residential multifamily buildings constructed in Bellevue:

- Type V, 1-Hour Construction;
- Maximum area of 42,000 square feet;
- Maximum of four storeys; and
- Maximum buildings height of 50 feet.

The Planning and Community Development Director noted that a fifth storey was currently allowed if the first storey of the building was constructed of non-combustible materials and if the building had a sprinkler system and fire-resistant components. He also noted that the Construction Code Advisory Committee recommended allowing an increase to five storeys, a 15-foot increase in building height, and a 25 percent increase in floor area for wood framed structures. Building size can be increased by providing firewalls between portions of the building meeting the maximum square footage. The Construction Code Advisory Committee recommended the following requirements for five-storey wood-framed buildings:

- National Fire Protection Association 13 sprinkler system (highest level protection sprinkler system) with quick response sprinkler heads.
- Pressurized stair enclosures and elevator shafts.
- Emergency power on site to ensure continuous operation of fire protection systems.
- Monitored automatic fire protection system.
- Structural observation to address shrinkage and compression issues associated with wood construction.

The Planning and Community Development Director stated that the communities of Burien, Everett, Federal Way, Portland, Seattle and Tacoma have all adopted provisions allowing five-storey wood-framed buildings and that Bellingham, Shoreline, and King County were all considering similar proposals. He also noted that the Construction Code Advisory Committee believed allowing five-storey wood-framed buildings offered a cost-effective alternative for Bellevue builders but recommended that five-storey wood-frame structures be limited to housing and office uses. The Planning and Community Development Director also noted that the proposed Building Code amendment would allow non-combustible fire construction, such as concrete for the first floor, topped by five storeys of wood framed construction (City of Bellevue, 2001 July).

The Washington State Fire Marshall noted that the Fire Department had reviewed and was supportive of the proposed Building Code amendment. The Fire Marshall also noted that jurisdictions that had adopted five-storey wood framed construction had not experienced any negative, unanticipated impacts. The Planning and Community Development Director stated that the additional height of 15 feet was consistent with the allowable building height of 65 feet for the next level of construction (City of Bellevue, 2001 July).

City Councillors also noted that the additional building height would provide greater flexibility for architectural design features and provide more housing opportunities, particularly in the downtown area. Also, that fire safety issues had been thoroughly discussed and evaluated by the Construction Code Advisory Committee and the Fire Department. The Planning and Community Development Director also confirmed that wood framed buildings were more affordable than concrete and steel structures (City of Bellevue, 2001 July).

The Planning and Community Development Director concluded by stating that he was confident that the proposed amendment would provide a level of protection equivalent to that proposed by four-storey wood framed structures and larger concrete and steel structures. Proceedings closed with the Bellevue Mayor noting Council's support for the proposal and asking staff to prepare an ordinance for Council's consideration (City of Bellevue, 2001 July).

2.2 Boise City, Idaho

Ordinance Adding a New Chapter to Regulate Construction of Mixed-Use, High Density Housing-August 2004

Web link: http://www.cityofboise.org/city_clerk/081704/Council/o-43-04.pdf

In August 2004, Boise City, Idaho approved the addition of a new chapter to the Boise City Code to regulate the construction of mixed-use, high density housing located within the Boise City Fire Department's Response Zone. This ordinance allows a builder to use wood to make buildings larger and taller than the code previously allowed. The ordinance was added because:

- Moderately priced housing was lacking and needed in the City's downtown core.
- Other communities have solved the above problem by adopting an ordinance that allows for less expensive building materials (wood) to be utilized.
- The ordinance added a number of life safety provisions beyond what the previous code required, so that less expensive materials (wood) may be utilized.
- The ordinance decreases car usage, as housing will be closer to work and shopping opportunities.
- The ordinance increases the viability of the City's downtown core as increased housing will support more downtown business.
- The ordinance increases building alternatives available to developers.

For single construction, the ordinance allows a five-storey wood frame building over a basement parking garage with a maximum height of five storeys that does not exceed 65 feet in overall height. For mixed construction, the ordinance allows a structure to be divided into an upper and lower building with a maximum height of 95 feet. The lower building may contain a basement and up to three storeys above grade being constructed of non-combustible material (steel and concrete) with the upper building height of a maximum of five storeys constructed of combustible wood frame construction. The upper and lower buildings are to be separated by a horizontal, three-hour fire-rated, floor/ceiling assembly. Floors constructed of combustible wood frame material are reserved for residential occupancy. The highest occupied level cannot exceed 75 feet above the lowest fire apparatus access road (Boise City, August 2004).

This ordinance does not allow the square footage increase usually allowed with the installation of a fire sprinkler system but does allow for an increase of 25% over the area listed under the previous code. Travel distances to exits in the combustible wood frame portion of the building must be reduced by 40% of what the previous code allowed. Exterior walls must be constructed to be a minimum 1-hour fire resistive and are required to have an exterior finished with non-combustible material. The ordinance increases the frequency of fire alarm maintenance and sprinkler inspections from once a year to quarterly, and requires special inspection to address critical design considerations related to wood shrinkage (Boise City, August 2004).

2.3 Portland, Oregon

City of Portland-Chapter 24.95 Special Design Standards for Five Storey Apartment Buildings

Web link:
http://www.portlandonline.com/Auditor/index.cfm?cce_28675_print=1&c=28675

The provisions of Chapter 24.95 allow for the construction of a five-storey, wood-frame apartment building. Single construction buildings complying with this chapter may be a maximum of five-storeys of combustible wood material. The occupancy of the top four floors is limited to apartments while occupancy of the bottom floor and/or basement is limited to offices; dining and drinking establishments; day care facilities; retail stores, and parking spaces/garages. *Six-storey* buildings complying with this chapter may be constructed if the first storey is constructed of non-combustible material and separated from five storeys of combustible material by a three hour occupancy separation (City of Portland, 2007 August).

All portions of the building are to be protected by an automatic sprinkler system which does not substitute for one-hour fire resistive construction and cannot be used as justification to increase the overall building area. The maximum height of any building cannot exceed 65 feet, measured from the lowest level of fire department vehicle access to the highest point of the building, excluding any mechanical, elevator or stairway penthouses. Access for fire fighting, rescue, and related purposes state fire department vehicle must be provided an access road and that at least 50% of all apartments with windows must be reachable by a ladder truck. At least two stairways must provide access to the roof (City of Portland, 2007 August).

2.4 King County, Washington

Five-Storey Wood-Frame Construction: Model Ordinance.
Web link: http://www.metrokc.gov/ddes/gmpc/housing/5strywd.doc

2.5 City of SeaTac, Washington.

Ordinance No. 04-1029: An Ordinance amending Section 13.110.020 of the SeaTac Municipal Code to allow five-storey, wood-framed buildings.
Web link: http://www.ci.seatac.wa.us/mcode/ordinances/04-1029.pdf

2.6 Des Moines, Washington.

Chapter 14.12 Five-Storey Wood-Frame Buildings.
Web link:
http://www.codepublishing.com/wa/desmoines/html/dmoins14/dmoins1412.html

2.7 Federal Way, Washington

Article IV. Five-Storey Wood-Frame Buildings.
Web link: http://www.mrsc.org/mc/fedway/fedwy05.html

3. Issues and Concerns

3.1 Pre-Completion Fire Prevention

There is not much information related to the area of pre-completion fire prevention. However, this topic may be of concern as efforts to push wood-frame construction over four-storeys moves forward. Although there is no evidence to confirm that multi-storey wood-frame structures are necessarily more at risk during construction than after completion it must be noted that there may be a phase of construction when the building is more vulnerable than at other times. One example of a pre-completion wood-frame fire occurred at the Kearney Plaza Apartment Complex in Portland, Oregon in August 1999.

The five-storey wood-framed Kearney Plaza quickly burnt to the ground. This occurred in part because fire safety features such as fire sprinklers had yet to be installed as only the skeletal frame of the building had reached completion. The cause of the fire was unknown; however, arson was suggested as a possible cause. To prevent this happening in the future the Portland Fire Bureau's Joint Code Committee considered applying new rules to the building of five-storey wood-framed structures, including (City Mulls, 1999 October 15):

- Posting an on-site security guard during hours when construction is not in progress;
- Requiring construction companies to assign staffers or hire subcontractors as construction fire-prevention oversight specialists;
- Activating sprinklers sooner in the construction progress;
- Requiring builders to install shear walls or other stabilizing systems to help ensure that critical structure components do not tip or fall into adjacent buildings;
- Requiring builders to temporarily compartmentalize buildings into smaller pieces during construction to reduce open, fire-prone spaces;
- Requiring builders to meet weekly with fire-bureau officials to ensure the builders are following preventive rules.

SUMMARY

The effort to amend legislation to allow the building of wood-framed structures over four-storeys is multi-jurisdictional. Over the past decade, several municipalities throughout the Pacific Northwest have rewritten building and fire codes to permit the building of five- and six-storey multi-use structures. Common among these jurisdictions has been the desire to increase urban density while providing citizens with additional affordable housing options. The assurance from engineers, fire marshals, and seismic experts that the safeness of wood-framed structures would not be jeopardized by allowing an increase in height restrictions has been central to any effort to amend previous legislation. It should be noted, however, that these examples are not directly transferable to a province-wide initiative. In particular, the cities did not further analysis of seismic risk for 6 storey wood-frame buildings as compared to 4 storey wood-frame buildings. The cities also had the advantage of input regarding building inspection practices and fire fighting capabilities of their communities. (rev 06.30.08)

Structural experimentation within the field of wood-framed building has bolstered efforts to increase the building height beyond four storeys. Projects undertaken in several countries throughout the world, including the United States, Italy, and New Zealand, is beginning to influence the engineering community (rev 06.30.08) that multi-storey wood-framed structures can withstand the force of an extreme seismic event. Engineers have also tackled several structural challenges related to wood frame construction including sound transmission, wood shrinkage, and fire safety issues. It must also be noted that in an era where environmental issues remain at the forefront, wood-framed structures exceed the sustainable capabilities of both concrete and steel framed buildings. Also, wood frame construction projects are built faster and are more cost effective than comparable steel- or concrete-framed buildings.

Beyond the issue of increased height are issues of whether to allow increased floor area and if there is an increased need for third party review of design and building inspections during construction. There will also likely be a need for increased education for the developers, contractors and the trades to support the successful construction of these multi-storey wood-framed buildings.

Based on the environmental benefits, recent technological improvements, and mounting evidence that concludes wood-framed structures over four storeys are both safe and reliable, the effort to amend legislation to allow builders to increase wood-framed buildings beyond four storeys should only continue to gain momentum.

Codes and standards are beginning to respond to the challenge. However, in order to avoid unintended tragedies such as loss of life due to fire or collapse during a seismic event or premature building envelope failure, it is important to ensure that codes are developed in a thorough and evidence-based manner with appropriate opportunities for public consultation. Pilot testing, for instance, of new code provisions is a tried and true approach to increasing the probability of success in the final regulatory requirements. (rev 06.30.08)

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APPENDIX A – SEARCH TERMS AND DATABASES

The Following Search Terms Were Used:

Building Code Amendments
Building Code Height Limit
B.C. Fire Code
Canadian Wood Council
Combustible Construction
Combustible Wood Construction
Fire Code Regulations
Fire Code Amendments
Five Over One
Five Over One Construction
Five-Story Wood-Frame
Five-Story Wood-Frame Construction
Five-Story Wood-Frame Fire
Height Limits
Kearney Plaza Apartment Fire
King County Building Officials
Mid-Rise Wood-Frame Construction
Portland Five-Story Wood-Frame
San Diego Five-Story Wood-Frame Construction
Seismic Multi-Story Wood-Frame
Six-Story Wood-Frame
Structural Engineering International
Tall Timber Buildings
Uniform Building Code
Uniform Building Code Amendments
Washington Association of Building Officials
Washington State Building Code

The Following Engines Were Used:

EbscoHost
Google
IngentaConnect

SENEZREEDCALDER
FIRE ENGINEERING INC

Review of Proposed Building Code Changes to Permit 5/6 Storey Wood-Frame Construction

Our File No: 908027
Date of Report: November 24, 2008

This Report Has Been Prepared For:

Building and Safety Policy Branch
Office of Housing and Construction Standards
4th Floor, 609 Broughton Street
Victoria, BC
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Senez Reed Calder Fire Engineering Inc.

Peter L. Senez, M.Eng., P.Eng.

Keith D. Calder, M.Eng., P.Eng.

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1.0 SCOPE AND CONTEXT OF REVIEW

This report has been prepared at the request of the Building and Safety Policy Branch of the Office of Housing and Construction Standards in British Columbia, and is intended to:

- Comment on the proposed changes to the code as outlined in the Stage 2 Report **DRAFT** Recommended Building Code Changes to Permit 5 and 6 Storey Wood-frame Buildings of Residential Occupancy, prepared jointly by GHL Consultants Ltd. and Read Jones Christoffersen Consulting Engineers.
- Summarize our fire loss experience with respect to building construction and make recommendations that could supplement the proposed changes. The scope of this report is relative to completed buildings with all fire protection systems in place, and not buildings under construction.
- Provide commentary on the risk versus the cost/benefit in implementing the different requirements.

Further, and as requested, RKTG Consulting Engineers and Busque Engineering Ltd. were retained to provide comments on the proposed changes to structural and building envelope aspects, respectively. Their reports are included in **Appendices A** and **B** to this report.

2.0 PROPOSED CHANGES AND COMMENTARY

The GHL Stage 2 report developed 14 proposed Part 3 and Appendix reference changes and 2 corresponding amendments to Appendix D of the British Columbia Building Code (BCBC).

The primary recommendations of the GHL report are to:

- Permit up to six storeys in building height while reducing to building area for each additional storey;
- Increase the reliability for floor and wall fire separations by including a second layer of gypsum board;
- Incorporate noncombustible cladding with exceptions for vinyl siding and fire-retardant treated wood shakes;
- Allow greater use of horizontal exits and the use of hold-open devices;
- Provide additional technical review to verify the integrity of compartmentalization.

The approach to building area and height is consistent with the evolution of the current BCBC requirements that permit the use of combustible construction. As outlined in the GHL report, accepting the proposed changes the government acknowledges and accepts all risks associated with the Code changes.

2.1 BUILDING CODE RISK CONTEXT FOR FIRE AND LIFE SAFETY

As outlined in our report dated October 15, 2008, the context of the building area and height requirements to permit combustible construction in the BCBC is not reflective of modern technology, knowledge, or construction methods. Over time, the National Building Code of Canada (NBC) was revised to adapt to its different formats, and only in the later editions of the code was it modified based on fire research. However, the modifications were incremental and today's BCBC still coincides with the premise from early 1900's relative to allowable building height and area.

The current BCBC is legally adopted into practice and therefore constitutes the accepted minimum level of risk. However, there is currently no measurable method applied in the industry to quantify the cost/benefit relative to the overall risk within Part 3 of the BCBC. Therefore, a qualitative approach is required which is more prone to interpretation than a quantitative approach. The framework for the current building code could better be described as a perceived risk as even in a qualitative context, the context to which fire behaviour is considered will be dependent on the knowledge and experience of fire behaviour relative to building construction.

In the development of the building code requirements for combustible construction in the BCBC, there is no reference to a risk based approach through the entire history of the code originating from the 1941 NBC. Further, there is no basis upon which to determine the basis for gauging the perceived risk as code changes were made. Consequently, there is currently no measurable method applied in the industry to quantify the risk/cost/benefit of a code change to increase storey height or building area in broadening the use of combustible construction.

It follows that increasing the height of combustible buildings can achieve the intended level of fire and life safety if it can be shown that the level of risk is either reduced or remains consistent with that expected by the current code.

2.2 REVIEW OF PROPOSED BCBC CODE CHANGES IN THE GHL REPORT

The GHL report proposed a series of code changes summarized in **Table 1**.

Our approach to analyzing the proposed changes considers the added value of each code change relative to its maintaining or decreasing the level of fire protection and life safety risk present within the current code requirements. The risk is then considered relative to magnitude of its potential increased costs, in order to realize whether the change is a cost-benefit.

In order to qualitatively measure risk, each change is evaluated relative to the potential to limit fire spread, limit the growth of fire, or facilitate evacuation and exiting. This is considered in conjunction with our experience addressing building code issues in actual fire loss applications. This approach considers each of the changes relative to their potential qualitative value to reduce the propensity for large loss fires. When considered in this context, a different approach can be used to quantify the potential cost/benefit and risk factors in making code changes.

The outcome of the analysis is supportive of the initiative to increase storey height as certain mechanisms that facilitate large loss fires are addressed. A summary of our perspective on the changes is included in **Table 1**. The following is a synopsis with respect to the major code changes:

1. The proposal for increased height will provide a greater level of fire protection and life safety to that currently afforded in existing four storey buildings where exterior fire spread is addressed through
    a. limitation on cladding systems, and
    b. sprinkler protection of large concealed spaces such as roof and crawl spaces.
2. The proposal for use of vinyl siding and fire retardant treated cedar shakes would require that the following be addressed:
    a. Part 3 of the BCBC does not define vinyl siding. There is a reference to CAN/CGSB-41.24 in both Part 5 of the code and Part 9 of the BCBC. This standard requires compliance with ASTM D635, "Standard Test Method for Rate of Burning and/or Extent and Time of Burning of Plastics in a Horizontal Position." This test method was developed for polymeric materials used for parts in devices and appliances. As outlined within,

    > [the ASTM D635] *standard is used to measure and describe the response of materials, products, or assemblies to heat and flame under controlled conditions, but does not by itself incorporate all factors required for fire hazards or fire risk assessment of materials, products, or assemblies under actual fire conditions.*

    The potential variability of vinyl products and their fire performance would likely require further consideration prior to incorporating a general allowance for vinyl siding, when compliance with ULC-S134 is a performance solution.
3. The GHL proposal follows a pattern of limiting building area that is consistent with the current code methodology. The proposed reduction in areas for 5 and 6 storey wood frame buildings would be disadvantageous from a cost/benefit standpoint. Further consideration of building area limitations is warranted, as outlined later in this report.
4. Fire protection rated membranes are a secondary line of defense for fires developing from floor areas of sprinklered buildings. Our loss experience suggests that a single layer of gypsum board is sufficient to contain a floor area fire to the compartment of origin. A second layer would add a substantial cost increase (2 layers of board as opposed to one) to achieve a minor potential incremental benefit.

Other aspects of the proposed changes are discussed in the sections that follow. A discussion on our loss experience resulting from the investigation of fires in existing 3 and 4 storey buildings both sprinklered and unsprinklered is provided in **Section 3.0**. A more detailed discussion on risk/cost/benefit relative to the proposed changes is provided in **Section 4.0**.

Table 1 : GHL Proposed Code Changes and SRC Commentary

Item	Issue	Solution Proposed by the Code Change	Division B Reference	SRC Comment
1	Building height	Permit 5 and 6 storeys.	3.2.2.45.(1)	Agree-in-principle
2	Building area	Limit building area to 5 storey at 1440 m^2 and 6 storey at 1200 m^2.	3.2.2.45.(1)	Agree-in-principle – consider cost/benefit/risk assessment to allow increased building areas
3	Building shrinkage	An appendix note reminding designers that design of 5 and 6 storey wood-frame buildings shall include consideration for shrinkage.	A-3.2.2.45.(1)	Agree-in-principle – move to Part 4 Structural
4	Qualification of designers	An appendix note stating the need for qualified professionals and Best Practices Guides.	A-3.2.2.45.(1)	Consider further review – code and specialist expertise may not be available in all jurisdictions
5	Fire rated floor assembly	Increase reliability of floor FRR	3.2.2.45.(5)	Consider further review - see discussion on risk/cost benefit
6	Fire rated floor assembly	An appendix note explaining the intent of item 5.	A-.2.2.45.(5)	Consider further review - see discussion on risk/cost benefit
7	Limitation on building physical height	Uppermost storey shall not exceed 18 m.	3.2.2.45.(6)	Agree-in-principle
8	Exterior cladding	Noncombustible exterior cladding. Combustible cladding permitted only if it meets CAN/ULC-S134, or vinyl on GWB cladding. Also explicitly permit use of wood nailing elements when conditions are met.	3.1.4.1.(1), (3), (4), (5), and (6)	Agree-in-principle - see SRC loss experience. Disagree on provision of requirements for exterior vinyl siding or fire retardant shakes.
9	Use of horizontal exit	Permit the required exits in a floor area to be entirely consists of horizontal exits, if the exits lead to a floor area that has exit stairs.	3.4.1.6.(1) and (3)	Neutral – see discussion on egress
10	Use of hold-open device	Permit use of hold open devices for horizontal exits.	3.1.8.12.(1)	Neutral – see discussion on egress
11	Balcony sprinkler	Sprinklers in balconies exceeding 600 mm in depth.	3.2.5.13.(9)	Consider further review – see discussion on risk/cost benefit
12	Vertical concealed spaces	Address fire spread in vertical concealed spaces.	3.1.11.5.(3)	Consider further review as to necessity of requirement
13	Exit fire separation	Increase reliability of exit fire separation.	3.4.4.1.(4)	Consider further review – see discussion on risk/cost benefit
14	Exit fire separation	Appendix A note explaining the intent of Item 14.	A-3.4.4.1.(4)	Consider further review – see discussion on risk/cost benefit
15	Limited ULC tested designs	Permit in Appendix D-2.3.3. the use of double layer designs when supported by appropriate fire test data.	D-2.3.3.(4)	Consider further review – see discussion on risk/cost benefit
16	Reference to NRC documents	Add to the current list of fire test reports in D-6.1. the NRC fire tests on floor and wall assemblies.	D-6.1	Consider further review – see discussion on risk/cost benefit

3.0 SUMMARY OF SRC LOSS EXPERIENCE

Senez Reed Calder Forensic Engineering Ltd., a sister firm to Senez Reed Calder Fire Engineering Inc., is engaged in the practice of investigating fires and analyzing building construction relative to fire growth and spread. The company actively investigates hundreds of mostly large loss fires each year, and has directly examined fire growth/spread mechanisms and other issues relative to combustible construction.

In analyzing large loss fires in completed buildings of combustible construction, we note the following experience:

Floor Area Fires (Sprinklers)

- The spread of fires in sprinklered buildings of combustible construction has been controlled by sprinklers where the fire is initiating inside the floor area of the building. The primary form of control in sprinklered buildings is by means of active suppression and therefore the secondary fire-rated membranes are only challenged when the sprinkler system fails. During the course of a sprinkler-controlled fire, the fire rated membranes act primarily for smoke control.
- In unsprinklered buildings, point source floor areas fires are generally controlled to the suite or compartment of origin, unless aided on the exterior by combustible cladding. Limiting the spread of these fires internal to the building has been achieved through the current passive measures of the code in requiring compartmentalization.

Concealed Spaces Fires

- Fires developing in concealed wall and ceiling spaces have spread where there are deficiencies in the fire stopping/blocking within the cavities.
- Fires developing in concealed wall and ceiling spaces that have been properly fire blocked are generally contained to the concealed space.
- Large fires can develop in crawl spaces and roof cavities and impact the entire building structure either due to collapse, drop down, water damage, or the complications of the subsequent repair.

Exterior Fires

- Large fires can develop up a combustible façade of a building, whether originating from within the floor area in an unsprinklered building or on the exterior of a building such as on a patio or balcony.
- Fires that develop on the exterior of the building, whether sprinklered (to NFPA 13R) or unsprinklered, can propagate into the roof concealed space (which is unsprinklered) and result in extensive damage to the building well beyond the suite or area of origin of the fire.
- Fires originating from the exterior of the building can go undetected for long periods of time allowing for greater fire development before detection.

Our experience in reviewing the growth and spread of fires in combustible frame buildings indicates that the weak points within the context of the current building code requirements is not relative to the floor area but on the exterior and within concealed spaces of the building. These fires are more likely to propagate well beyond the localized origin, resulting in a much greater fire and water damage. Therefore, instead of having a localized fire confined to one suite with smoke and water damage on the periphery, it is not uncommon to see entire sections of the wood-frame building fire damaged, with the roof destroyed, and water damage throughout.

4.0 RISK/COST-BENEFIT OF PROPOSED CHANGE IMPLEMENTATION

The framework for gathering statistical data in British Columbia does not correlate with the individual requirements in the building code. Therefore, although it may be possible to filter the data in an approximate fashion to consider fire damage in combustible buildings, this information will not identify aspects of combustible construction that may be more prone to allowing for large loss fires.

If we consider the loss experience described in the previous section of this report, an alternative strategy would be to regulate mechanisms that would facilitate the development of fire propagation within wood-frame buildings in order to optimize the existing compartmentalization requirements.

These concepts can further allow considerations on a cost-benefit basis in order to incorporate changes to the code that add the most value in limiting risk, while forgoing other more onerous changes that have only marginal value. This approach would therefore consider the proposed changes in a different light and provide for other changes that allow for overall risk reduction over the current basis of the code.

4.1 COMPARTMENTALIZATION

The BC Building code addresses fire spread internal to the building through the provision of fire separations between residential units, public corridors, service rooms, floor areas and shafts.

The GHL code changes propose maintaining the current concept of maximum gross floor area that would reduce the overall building area to 1220 m^2 for a six storey building from the current 1800 m^2 for a combustible sprinklered 4 storey building. In this concept, the overall fuel load between firewalls or spatially separated buildings would not change, and correspondingly there is no qualitative increase in risk.

However, this risk concept is based on a total failure of the building and the subsequent involvement of all of the building framing and contents. In isolation to the other changes proposed, increasing the building height would facilitate fire spread and subsequent water damage. This increase is alleviated through the code change proposal for noncombustible exterior cladding; however, the greater risk to water damage to multiple storeys of the building would still remain.

It is unclear how the proposal would offer a significant advantage to the construction industry as it would have the same or a reduced number of suites within the same volumetric space. This may increase the flexibility of building configurations on small lots, but will not allow greater floor area available for occupancy. Therefore, the extent to which the proposal would achieve value may need to be considered further from an economic perspective.

In today's gypsum board protected, significantly compartmentalized, completed wood frame buildings, the potential for involvement of the entire structure is significantly reduced from the era that the height and area limitations were developed (the 1910's).

In considering the loss experience described in the previous section, the potential for large loss fires in buildings can be significantly reduced through:

1. Controlling fire spread on the exterior of buildings in the form of noncombustible or fire spread limiting materials. Exterior cladding is the most significant mechanism for large loss fires spreading beyond the compartment of origin.

   In this regard, the proposal in the GHL recommendations for noncombustible cladding would achieve this objective. However, until further study is completed to support the other proposed systems, it would be prudent to limit the scope to noncombustible construction (including ULC S134 systems).

2. Eliminating crawl spaces and open roof spaces that are not sprinklered.
3. Providing roof venting from the top and eliminating open soffits above openings.

The implementation of the above recommendations would substantially reduce the potential for multiple fire compartments within a building becoming involved in fire, and in turn, substantially reduce the qualitative risk associated with existing wood-frame construction. Therefore, a five and six storey wood-frame building would be less risk than current 3 and 4 storey wood-frame buildings.

In doing so,

4. Consideration could be given to increasing, or maintaining the building area for a 4 storey combustible building (1800 m^2) in the 5 and 6 storey applications.

This methodology would be consistent with that adopted by some European countries which limit construction requirements through compartmentalization.

It is advantageous to have commercial space on a main level in today's neighborhood housing and increased building density. However, when several combustible buildings are constructed above noncombustible slabs, issues with continuity of firewalls impede the ease at which these buildings can be developed within the current code. The use of commercial space on the lower level generally eliminates the need for crawl spaces and would consequently reduce the need for a large open area beneath multiple residential suites.

The BCBC currently has a similar framework for the construction of buildings above parking structures under the requirements of 3.2.1.2. in Division B, Part 3 of the BCBC. Extending this rationale to above grade commercial levels would facilitate the provision of assembly, shops, and retail facilities.

Conceptually, this would allow for one or two levels of commercial with a 2 hour slab separating combustible components. The main advantage would be to:

5. Allow firewalls separating combustible buildings to terminate at a 2 hour concrete or masonry horizontal slab at either the first or second storey. This would offset the need to extend the firewall through the lower levels of the building. This delineates the building area of combustible construction and greatly increases flexibility on the lower levels.

The above would eliminate the risks associated with concealed crawl spaces, while allowing construction of lower levels in accordance with the requirements for noncombustible construction. This would lower the overall risk to the presence of combustible construction on the project with any risks associated with a commercial level being addressed by other parts of the BCBC. The risk/cost-benefit associated with these changes would likely realize good value and meet the objectives of the current BCBC.

4.2 Fire-Rated Membranes

Our experience relative to the performance of a single layer of gypsum board in fire compartment exposed to floor area fires would not support the costs associated with additional layers of gypsum board as proposed in the GHL recommendations. In unsprinklered wood-frame building fires, the fire-rated membranes have generally limited the propagation of fire to the compartment of origin. In sprinklered buildings, floor area fires are generally contained by the sprinkler system. Therefore, the fire-rated membrane in sprinklered buildings serves as a redundant passive system to the primary active system.

The GHL proposal would add significant cost to the construction of a project, reduce accessibility within the floors for fire departments to attack concealed space fires, and increase the costs of overhaul and repair following a fire.

Given limited loss experience to correlate a significant risk to fire spread, the proposal would offer reduced cost/benefit with a minor decrease in risk.

4.3 Active Fire Suppression

The GHL proposal recommends adopting the NFPA 13 standard for sprinklers along with a proposal from the City of Vancouver with respect to balconies. Since NFPA 13R is limited to four storey buildings, this change will be automatic.

The City of Vancouver requirement for sprinklers on balconies over 600 mm was derived based on the presence of combustible cladding in buildings following experience of Vancouver Fire & Rescue Services with barbeques on balconies. It was intended to address buildings sprinklered according to NFPA 13R. No technical basis could be determined for the 600 mm criteria.

The potential for fire propagation from a balcony is proposed to be controlled through the use of noncombustible cladding materials. Since the City of Vancouver requirement was derived for purposes of addressing balconies with combustible cladding the cost/benefit of adopting a change to balcony sprinkler protection beyond the requirements of NFPA 13 is unlikely to add a measurable improvement to the overall life safety risk.

4.4 FIRE ALARM AND EGRESS

The concepts on fire alarming contained within the BCBC have not been altered in many years. However, the technology of modern addressable systems allow for greater knowledge and interpretation of data than has previously existed. Egress and exiting is generally addressed in the BCBC by regulating travel distance and allowing areas that provide temporary protection from the fire and smoke. The underlying presumption is that people will leave when the alarm sounds.

Buildings are often designed and separated for purposes of determining construction requirements but are interactively dependent from a fire alarm standpoint. Addressing evacuation concepts and movement of people to increasing zones of safety through horizontal exiting and/or movement to increasing levels of protection allows the fire department better facility to source the fire and facilitate evacuation on a priority basis. The GHL proposal to allow for horizontal exits is a global issue and should be considered for all applications, and not just five and six storey applications.

The human behavioural response to fire alarms has been researched in recent years, and the value of delivering information to occupants during a fire alarm condition provides a formidable way to effect a controlled evacuation and address behaviour response issues. These concepts are unaddressed in the current prescriptive framework of the code.

Applying a global approach incorporating horizontal movement would be advantageous in directing evacuation to those that may be reluctant to use or access stairs, such as persons with disabilities and seniors.

Some simple measures that would add value at relatively low cost include:

- The provision of a voice communication system,
- The use of at least one horizontal exit within a floor area (through a firewall) or the provision of a subdivided public corridor into two zones,
- Using staged alarming between fire alarmed buildings.

The above would be a high value offsetting measure in lieu of placing further restrictions on building area and would address the specific issues associated with increased building area - evacuation.

4.5 FIRE DEPARTMENT RESPONSE

The GHL report indicates that the primary fire department response, given a sprinklered building would be entry into the building to suppress the fire.

This is consistent with our observations of fire department response in 3 and 4 storey existing wood-frame buildings, including unsprinklered buildings. However, when fires have extended beyond the compartment of origin due to fire spread in concealed spaces, there has been a need for aerial ladders to assist in fire suppression.

Additional design features that would support fire suppression could include:

- The provision of fire walls to separate building components – allows one building to be used as a staging area for evacuation and suppression activities,
- The provision of access to attic spaces from any stairs.

Further, consideration could be given to:

- Reach and availability of aerial ladders to portions of the building perimeter,
- Water supply availability in the event of a sprinkler system failure.

5.0 SUMMARY

This report reviews the proposed building code changes to permit 5 and 6 storey residential buildings. These changes are being evaluated in the context of the BC Government's mandate to consider 5 and 6 storey buildings as a means to achieve more cost-effective housing.

The proposed Part 3 changes to the building code are technically supportable within the context of the current code requirements. The approach developed in this report provides a qualitative rationale to support 5 and 6 storey wood-frame buildings. The approach:

- Provides a basis to allow for greater building areas than proposed in the changes where wood-framing, combustible construction is used.
- Supports changes that limit wood-frame construction conditions that facilitate the potential for large loss fires in combustible buildings.
- Weighs the benefit of adding layers of gypsum board to increase redundancy on secondary passive fire membranes where experience has shown that single layered membranes have been effective.
- Improves safety and reduces risk with modern fire alarm technology and strategize compartmentalization.
- Recognizes the available resources of modern fire departments.

This approach offers a better cost-benefit balance in weighing the potential value in the context of fire life safety that each change requires in combustible buildings constructed under the current BCBC combustible construction requirements. Applying a risk/cost-benefit approach could allow for increased building areas of combustible construction.

Our research into the conceptualization of building area and height requirements indicates that the technical formulation in defining the limits is lacking foundation, and does not address the potential that can be realized with today's knowledge of fire science, modern construction materials and methods, decades of improvements to fire alarm technology, and today's understanding of human response to fires and alarm. This is outside the limited scope of the current proposed changes; however, it could be addressed.

APPENDIX A

Letter from RKTG Associates Ltd. on Structural Aspects of Proposed Code Changes

RKTG
ROBERTSON
KOLBEINS
TEEVAN
GALLAHER
ASSOCIATES
LTD
CONSULTING ENGINEERS

November 1, 2008

Senez Reed Calder Forensic Engineering Ltd
Unit 520 – 5600 Parkwood Way
Richmond, B.C. V6V 2M2

Attention: Mr. Peter Senez

Dear Sir:

Re: Stage 2 Report (Draft) for 5 and 6 Storey Wood-Frame Buildings Group C

I am pleased to provide a few comments with respect to the proposed code changes based on an initial reading of the draft last week with respect to issues of structural integrity.

Pg 8 of 37 The structural engineer is required to identify building movement due to shrinkage *and compression of multiple wood assemblies* to the design team …..

Pg 12 of 37 … 18m criteria to the *roof* of the 6th storey … would be consistent with Appendix A and the general guide of 3m per floor.

Pg 15 and 18 of 37 rationale … rated structural capacity of attachments such as exterior cladding may not be available for wood furring strips and combustible wood cladding which are subject to deterioration. Durable non-combustible cladding above 12 m height is preferred at this time. This may be subject to a structural review of increased wind and seismic design loads and proposed cladding details in these areas of increased building exposure to assure a lifespan that is a reasonable fraction of the proposed lifespan of the core building.

Pg 21 of 37 With respect to travel distance and possible seismic damage to exit stairways, the increase in travel distance to 180 m (600 feet) to an alternate vertical exit is considerable. A maximum travel distance of 60m to an exit stairway on each floor is reasonable for residential occupancy and beneficial such that at least one exit stairway exists for each independent building.

Pg 31 of 37 5) For five and six storey wood-frame structures in seismic zones the stairwell woodframe shear walls shall be designed to restrict lateral drifts such that lower exit doors to the building exterior shall remain operational and functional after seismic yielding and permanent set.

Pg 31 of 37 6) For five and six storey wood-frame structures the bottom two floors shall be designed with D-Fir or engineered wood that is better able to adequately carry vertical loads from above stories without crushing when wood sills are wet with reduced load-bearing capacity. This requirement is based on a practical need to endure moisture temporarily and rehabilitate lower floors after fire suppression by removing wall finishes. Original building geometry shall be maintained.

I trust that you will find the above summary acceptable. If you have any questions please call.

Yours very truly,
RKTG ASSOCIATES LTD.

PROFESSIONAL ENGINEER — PROVINCE OF BRITISH COLUMBIA — ROBERT L. WILLS

Robert Wills, P. Eng., Struct. Eng.
B.C., Alberta, Yukon

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APPENDIX B

Letter from Busque Engineering Ltd. on Environmental Envelope Aspects of Proposed Code Changes

Busque Engineering Ltd.

File: 2008-002
Date: 03. Nov. 2008

Peter L. Senez, P.Eng.
SENEZ REED CALDER FIRE ENGINEERING INC.
520 - 5600 Parkwood Way, Richmond, BC,
V6V 2M2
CANADA

Email: psenez@flashover.ca

RE: Amending the Building Code to Permit Up to and Including 6 Storey Wood-Frame Buildings of Residential Occupancy, Stage 1 and Stage II Reports (the "Reports")

Dear Mr. Senez,

In this document, this proposed amendment, stated above in the reference header, will be referred to as the "Amendment".

As per your request, Busque Engineering Ltd. ("BEL") has reviewed the Reports to provide an opinion on the findings of the Reports with regards to the Amendment's impact on the Building Envelope.

BEL is in substantial agreement with the findings contained in the reports with one exception.

On Page 25 of the Stage 1 Report contains the following statements:
Risk of Failure of Environmental Separator, Leading to Safety Risk –Risk not likely to increase
"Part 5 provisions require the design of environmental separators to include building materials, components and assemblies to accommodate all loads, and resist any deterioration, that may be reasonably expected, given the exposure...."

My review of Part 5 did not uncover a reference to the environmental load represented by construction moisture. Past editions of the Part 5 of the British Columbia Building Code (BCBC), contained a clause that stated that "The design and structural requirements of other Parts of this Code shall apply." This clause permitted the design professional to enforce a Part 9 requirement that limited the moisture content of the wood use in constructing buildings. Part 5 of the 2006 Code does not contain such a statement.

Table 6 P. on Page 24, lists some of the Technical Risk that the 2006 Code addresses. One of these is the ***Structural safety risk due to failure of environmental separator*** corresponding to Code objectives OS 2 Structural Safety and OS 2.3 Damage to or deterioration of building elements.

In my opinion, constructing taller wood frame buildings will extend the exposure of the wood used to construct these buildings to moisture during the construction period. This signifies that wood is likely to be at a higher moisture content at the time that the other elements of the building envelope are installed. This may leave the building envelope more susceptible to damage from shrinkage of the wood frame or to deterioration due to construction moisture.

We recommend adding wording in the Amendment limiting the moisture content of wood in a building structure in order to avoid damage to the building envelope cause by shrinkage or deterioration of the wood frame.

Please do not hesitate to contact me if you wish to discuss.

Busque Engineering Ltd.
Per:

Pierre-Michel Busque, P.Eng.

SENEZREEDCALDER
FIRE ENGINEERING INC

A HISTORICAL PERSPECTIVE ON BUILDING HEIGHTS AND AREAS IN THE BRITISH COLUMBIA BUILDING CODE

OUR FILE NO: 908027
DATE OF REPORT: October 15, 2008

THIS REPORT HAS BEEN PREPARED FOR:
BUILDING AND SAFETY POLICY BRANCH
OFFICE OF HOUSING AND CONSTRUCTION STANDARDS
4TH FLOOR, 609 BROUGHTON STREET
VICTORIA, BC
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PREPARED BY:

SENEZ REED CALDER FIRE ENGINEERING INC.

Keith D. Calder, M.Eng., P.Eng.

PROFESSIONAL ENGINEER
PROVINCE OF BRITISH COLUMBIA
K. D. W. CALDER
29920

OCT 16, 2008

Peter L. Senez, M.Eng., P.Eng.

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1.0 INTRODUCTION AND SCOPE OF REPORT

This report has been prepared at the request of the Building and Safety Policy Branch of the Office of Housing and Construction Standards in British Columbia, and responds to three questions pertaining to the basis and development of the height and area requirements for combustible residential construction in the current edition of the British Columbia Building Code (2006 Edition). The three questions are:

1. What is the historical rationale for limiting the height and area of combustible residential construction to 3 storeys for an unsprinklered building and 4 storeys for a sprinklered building?
2. How has the building code, relative to the construction requirements for residential construction, adapted to recognize the benefits of sprinklering? And does sprinklering a residential building provide a new rationale for reconsidering the underlying assumptions affecting height and area of a building?
3. Is there a different rationale underlying the assumptions in the International Building Code (United States) vis-à-vis height and area compared to those in the BC Building Code and is it possible to use these IBC assumptions to reconsider the rationale for our height and area calculations?

Answering these questions requires an examination of the historical record of code development in Canada and the United States. The Canadian building code system is similar to that of the United States in its origin and application. In both countries the "model code" is developed by committee and adopted at a provincial or state level with local modifications.

The BC Building Code (BCBC) has been based on the National Building Code of Canada (NBC) since 1987. Prior to that the NBC was adopted outright with minor modifications made usually at the municipal level. The system in the United States resulted in several model codes being developed, three of which were recently amalgamated into the International Building Code.

Within the Canadian or American code development, the height and area limitations can be traced back to the same root origins; therefore, the premises of the codes are the same. It is the subsequent development and changes to the code that differ. To consider the origin of the 2006 BCBC requirements, an examination of the historical height and area limitations in the NBC and US model codes is required.

The first edition of Canada's National Building Code was published in 1941 and was based on the US model codes available at that time. The development of the Canadian and US model codes originated out of a need to regulate construction on a national basis. Most of the requirements in both the Canadian and US building codes were developed based on large city regulations in existence at the time of their development, with the intention of limiting large catastrophic fire events such as conflagrations or fires with large life loss.

This report will illustrate that the height and area requirements were primarily developed as a passive measure to mitigate the perceived risk to life and property in the early 1900's – and were based on the understood capabilities of the fire departments at that time. The information has been assembled from numerous sources with an approximately similar date of publication. Not all of these sources can be linked directly to development of the requirements in one particular model code since the development process is not apparent, and documentation of the process is not available. Nevertheless, when examining the technical documents available at the time of their development, there are appreciable consistencies that can be used to make strong inference as to the development of the height and area requirements.

2.0 ORIGINS OF THE NATIONAL BUILDING CODE OF CANADA

An examination of the development of the National Building Code of Canada (NBC) is important when considering the technical basis for the requirements contained within. The early development of the NBC was strongly linked to the development of the US model building codes at that time to reduce any reproduction of work already completed and recognizing similarities in construction conditions.

The British North America Act (previously the Constitution Act) delegated the responsibility of building regulation to the provinces and territories. Prior to the development of the first model building code in Canada in 1941 (1941 NBC), municipalities were often tasked by the Provinces and Territories with building regulation. Large municipalities (cities) had the resources to develop building regulations, and needed them to regulate the construction booms in the larger cities at the turn of the century. Smaller cities and towns did not have the resources or technical ability to develop building regulations, and often had none. These local building regulations were specific to the local needs, and varied from city to city. Some requirements had a technical rationale, others were based on assumptions or were simply an approximation or estimation at the time they were developed. This local type of building code development made for an inconsistent system of regulation and led to inconsistency and confusion in the construction industry within Canada. Similar problems were occurring in the United States albeit, several decades earlier. An excerpt from a US Senate Committee on Reconstruction and Production relative to the condition in the States in the 1910's suggests that:

> *The building codes of the country have not been developed upon scientific data, but rather on compromises; they are not uniform in principle and in many instances involve an additional cost of construction without assuring more useful or more durable buildings.*

Development of a model building code was first contemplated in Canada in the 1920's; however, was abandoned because there was no Canadian organization in a position to write suitable specifications[1]. At the same time, development of a model code was underway in the United States. The process was re-initiated in Canada in the 1930's by several construction associations in discussion with the National Research Council of Canada (NRC). An associate committee was formed in 1932 with an initial task of unifying the building codes throughout the country. In 1937 Mr. A.F. Gill of the NRC prepared a paper, "A National Building Code," outlining work at that time on development of a model code and recommended an approach to bringing such a code document together[2]. In recommending an approach, Gill's paper identified the large amount of work completed in the United States relative to a model code and suggests that given the similarities between the United States and Canada, that:

> *any building code authority in Canada could do no better than adhere to the procedure followed by American authorities and take advantage of their recommendations.*

Gill was referring to the development of model building regulations under the authority of the Department of Commerce in their "Elimination of Waste Series," comprised of several documents published between 1923 and 1935. These documents were prepared under the technical direction of the Bureau of Standards[a], and based largely on existing "large city" regulations with refinements

[a] The Bureau of Standards became the National Bureau of Standards and eventually the National Institute of Standards and Technology today.

made where supported by technical information available at the time of their adoption. Most of these requirements originated from the local codes that existed in New York, Philadelphia, Boston, Chicago and Baltimore. These were all cities in which large conflagrations had occurred, accelerating the development of local building regulations.

Using the "Elimination of Waste Series" as a recommended technical basis, the first complete version of the National Building Code of Canada was published in November of 1941 (1941 NBC). Construction technology, materials and methodologies constantly change. Since the development of the 1941 NBC, technological advances resulting from the Second World War made revisiting the NBC important to verify it was still fulfilling its intended purpose. As a result, two dozen Canadian individuals with relevant expertise were selected from representative geographical locations within Canada to form an Associate Committee whose purpose was (and still is) to promote uniformity of building regulations throughout Canada and to maintain the NBC as an up-to-date and progressive document[3].

The purpose behind the continued development of the NBC by the Associate Committee is to embrace new technologies, materials and methodologies. This has occurred throughout the development history of the NBC with significant development in areas such as spatial separation, interconnected floor space and highrise requirements. However, the NBC has not changed significantly relative to allowable building heights and areas. The most appreciable changes relative to residential construction have occurred within the last 20 years, and will be discussed in more detail in a **Section 3.0** of this report.

The difficulty with making any changes to existing building code requirements is having an understanding of the historical rationale of those requirements. This is especially true for the legacy requirements that predate the development of the 1941 NBC that were adopted with minor modifications, as is the case for the height and area requirements. Formulating a means for reassessing those requirements within the context of a new technology, materials or methodologies is difficult, without their original objective and basis for development.

The purpose of the following sections of this report is to outline the origin and basis for the development of the height and area requirements, relative to combustible residential construction, in the US and Canadian model codes by answering the 3 questions posed.

3.0 QUESTION 1: HISTORICAL RATIONALE

Question 1:

> *What is the historical rationale for limiting the height and area of combustible residential construction to 3 storeys for an unsprinklered building and 4 storeys for a sprinklered building?*

3.1 BUILDING HEIGHT

Building height has been regulated in parts of the United States, UK and Canada since the late 1800's. Initially the purpose of regulating building height was to enhance natural lighting and ventilation for purposes of health. However, this typically was not the case for residential wood framed buildings whose height was restricted more for purposes of fire-fighting and egress. For example, the London Building Act of 1894 allowed the London County Council to require special escape facilities from new buildings over 18 m in height with the need to use fire resisting materials for high buildings. After some fires in 1899 the Metropolitan Fire Brigade reported that a height of 15 m was the limit of rescue by ladders, and the London Building Acts (Amendment) Act 1905 reduced the limit from 18 to 15 m and applied the control to existing buildings as well[4].

Similar requirements were implemented in the US in the early 1920's. The building code published by the National Board of Fire Underwriters of New York suggested that[5]:

> *It is generally conceded that five stories is the maximum height to which water can be thrown effectively by a fire department from the street level, and that 50 feet is the maximum distance inside a building which can be reached by a stream through a window. These facts have been a governing consideration in the establishment of the limits of heights and areas in this Code. In addition, the width of the street upon which a building fronts and the height of the building should be considered; a building endangers adjacent property in proportion to its size and proximity to other property.*
>
> *The term street as here used, is a public thoroughfare at least 20 feet wide.*
>
> *The areas given in this section are based upon an average street width of 60 feet. For less than this width, it does not appear unreasonable to require sprinklers for even smaller areas than herein given, particularly for buildings over two stories high. This could well be placed in the hands of the Chief of the Fire Department.*

The ability of a fire department to fight a fire was largely dependent on the available equipment and capability of that particular department. In North America, fire departments had (and still have) varied capabilities and resource allocations. This potential diversity in fire department capability was addressed more specifically as outlined in the "Recommended Minimum Requirements for Fire Resistance in Buildings" (1931 NBS) reference document from their "Elimination of Waste Series," which stated that:

> *The height at which construction requirements should become more drastic from a fire-resistance standpoint is determined very largely by the height above which a city fire department can not cope successfully with fire from the exterior of a building because of limitations of water pressure and apparatus. This limit will vary to some extent in different cities, and building codes should vary accordingly[6].*

For residential construction, the 1931 NBS document recommended a building height of 2 storeys for unprotected wood frame, 3 storeys for masonry and wood joist, and 4 storeys for heavy timber construction. These types of construction differ from current construction types in the NBC; however, are clarified for the purposes of establishing what type of construction should be considered as combustible versus noncombustible and protected versus unprotected in Canada[7]:

> *Combustible construction is usually considered to be conventional wood frame or heavy timber construction. Conventional wood frame construction is described in considerable detail in Section 9.23 of the NBC. Heavy timber construction is a special category of combustible construction and is considered to be acceptable where combustible construction having a ¾ h fire-resistance rating would normally be required.*

The consistency in building height from the change between heavy timber and protected ¾ hour construction can be seen in the historical changes to the NBC, as shown in **Table 1** below.

Table 1: Building Height Limitations in the NBC.

NBC	Construction	Unsprinklered	Sprinklered
1941	Wood frame	2	2
	Masonry and Wood frame	3	3
	Heavy Timber	4	4
1953	Non-protected Combustible	1	1
	Protected Combustible ¾ hour rating	2	2
	Heavy Timber	3	3
1960 to 1985	¾ hour Fire Separation	3	3
1990 to 2005	¾ hour Fire Separation	3	3
	1 hour Fire Separation	3	4

The change in allowable building height for heavy timber in the 1953 NBC is consistent with that for combustible construction having a ¾-hour fire-resistance rating in the later editions of the NBC. From the 1953 edition of the NBC to the current edition, the height limitation of a combustible residential building was 3 storeys unless it was sprinklered, which in 1990 permitted 4 storeys.

Permitting 4 storeys in building height for a combustible residential building equipped with an automatic sprinkler system recognized the benefits of sprinklers in controlling fires and the effects of fire. This benefit was the basis for allowing the additional storey of building height, which was identified in a paper presented by J.R. Mehaffey on "Combustibility of Building Materials," at a seminar on "Designing for Fire Safety - The Science and its Application to Building Codes," which states that:

> *Evacuation and fire fighting activities are assumed [in the 1985 NBC] to proceed more smoothly in sprinklered buildings, in buildings of fewer storeys and smaller area, and where there is direct access for fire fighters from more sides.*

Quantifying the benefit associated with the provision of sprinklers will be discussed in more detail in **Section 4.0** of this report.

3.2 Building Area

The limitations on building area have a much more complicated historical basis than for height. The area limitations were first contemplated at a time when city wide conflagrations were not an uncommon occurrence in the United States and Canada. One fire in particular, occurred in Baltimore Maryland in 1904, resulting in approximately $50 million in damage to the city. The National Fire Protection Association conducted a review of the fire damage on a building-by-building basis and made recommendations on various aspects of fire prevention. One of the observations was that[8]:

> *[l]arge unbroken floor areas assist the spread of fire and serve to augment its severity. Buildings of considerable area and having large quantities of combustible contents should be subdivided by substantial brick fire walls sufficient to form a positive barrier to the spread of fire.*
>
> *It was noticeable even in office buildings that the damage was generally greatest where there were large offices without any subdividing partitions.*

This observation identified large unbroken floor areas as a risk to significant fire spread back in the early 1900's. Another large conflagration occurred in 1906 after an earthquake in San Francisco. Similar observations were made following an assessment of the damages of that fire. Specifically[9]:

> *The subdivision of floor areas will largely serve to prevent strong draughts of air from one side or portion of a building to another side or portion, thereby greatly avoiding the hazardous conditions of severe exposure fire or wide-spread conflagration. It was found in both the Baltimore and San Francisco conflagrations that fire not only swept through undivided floors with greater rapidity than in divided areas (as would naturally be expected), but with greater intensity as well. In other words, each horizontal story becomes a flue, the length of which is the distance from the window openings lying nearest the exposure to those in the opposite wall.*

Building area limitations were developed to address egress, fire department access, fire spread within the building and to adjacent buildings. This was identified in a handbook on "Fire Prevention and Fire Protection as Applied to Building Construction," which suggested that subdivision of large floor areas by fire-resisting walls, aside from the question of egress, was intended[9]:

1. *To localize or confine internal fire, so that it need not spread beyond the unit of area in which it originates, thus effectively limiting the fire damage and consequent financial loss.*
2. *To minimize the damage resulting from severe exposure or conflagration conditions, by breaking up large undivided floor areas into efficiently surrounded units.*
3. *To aid fire-department work in the extinguishment of fire.*

One of the earliest known references to limiting the floor area of a building is the 1901 edition of the New York Building Code. This code limited the area of a store, factory, hotel or lodging house based on the number of egress stairs provided by units of 5000 square feet[10]. The basis for limiting the building area to 5000 square feet in New York was justified as follows[9]:

> *It has been pointed out that the volume and intensity of fire, and the rapidity with which it will gain headway, are all vastly greater in large areas than in small ones. It*

> *is also a much more difficult matter for a fire department effectively to surround and fight a fire of large area. Much valuable time is lost in running long lines of hose, in addition to which, smoke conditions are often so bad that the actual location of the fire cannot either be found, or reached if found. There is a limit to the ability of firemen to inhale smoke or withstand heat, and once this limit is reached, the offensive operations of extinction cease, the firemen are put on the defensive, and the fire is master of the situation. These considerations would point to the desirability of fixing what might be termed the maximum area which can be efficiently handled by a city fire department. "As a working unit, 5000 square feet has been suggested, with a limit of 100 feet in any direction (or a rectangle 50 by 100), which is as large an undivided area as the experience of the New York Fire Department indicates to be within the capacities of effective fire department operations."*

The 5000 square foot limit was based on the experience of the New York Fire Department. Since the restriction on building area was formed on the basis of the capability of the responding fire department, applying an area restriction on a national basis required a survey of the experience of various fire departments. This type of survey was conducted in 1913 relative to factory buildings[11], and focused on factory buildings because their construction up to the 1920's was long thought of as posing a grave danger to life and property. The Author of the paper surveyed over 100 fire chiefs representing cities with a population over 20,000. The results of the survey are summarized in **Table 2** below.

Table 2: Results of Fire Chief Survey.

Type of Building	Height (Storeys)	Area between Firewalls (ft^2)
Non-fireproof, not sprinklered	3	6,000
Fireproof, not sprinklered	5	10,000
Non-fireproof, sprinklered	5	13,000
Fireproof, sprinklered	8	20,000

* Average storey height was 12 to 13 feet.

The height and areas outlined in **Table 2** form the basis for many future height and area limitations, and was re-interpreted by subsequent building code committees as it applied more generally to the conditions within the US and Canada. Note that the areas permitted for sprinklered buildings were approximately twice that for buildings without sprinkler protection. This is discussed in more detail in the following section of this report.

One of the earliest references to limiting area (and height) for residential construction appears in the twenty fourth annual report (1920) of the NFPA Committee on Building Construction[12]. This report defined apartment house construction requirements based on three types of construction, as shown in **Table 3**.

Table 3: Building Area Limitations Proposed by the NFPA Committee on Building Construction.

	Type of Construction		
Design Feature	Grade A	Grade B	Grade C
Use of Wood	None permitted	Trim, finish, and floor surface	Permitted for any purpose other than lath and supporting structural members
Height	125 ft	100 ft	75 ft
Area	7500 ft²	6000 ft²	5000 ft²
Floor Separations	3-hours	2-hours	1-hour

The basis for limiting building area was intended to promote rapid egress, limit fire spread, and aide in fire suppression activities. This was considered paramount where the building structure was of combustible material that may potentially contribute to the growth and spread of a fire, and was the primary reason that additional floor area was permitted where the wood framing was protected by appropriate surface cladding such as gypsum board.

The building area limitations in the 1941 NBC were based on the same principles as those developed several decades earlier in the United States, and remained relatively consistent with subsequent editions of the NBC. However, small changes to allowable building areas were made between the 1941 NBC and the current edition. These changes are shown in **Table 4** and discussed in more detail below.

Table 4: Building Area Limitations in the NBC.

NBC	Construction	Unsprinklered		Sprinklered	
		Height (Storeys)	Area (m²)	Height (Storeys)	Area (m²)
1941	Unprotected Wood frame	1	750	1	1500
		2	500	2	1000
	Masonry and Wood frame	1	750	1	1500
		2	500	2	1000
		3	500	3	1000
	Heavy Timber	1	2250	1	4500
		2	1500	2	3000
		3	1500	3	3000
		4	1500	4	3000
1953	Unprotected Wood frame	1	500	1	1000
	¾ hour rating	1	1800	1	3600
		2	600	2	1200
	Heavy Timber	1	2400	1	4800
		2	800	2	1600
		3	800	3	1600

NBC	Construction	Unsprinklered		Sprinklered	
		Height (Storeys)	Area (m²)	Height (Storeys)	Area (m²)
1960 to 1965	¾ hour rating	1	1000	1	2000
		2	600	2	1200
		3	600	3	1200
1970 to 1985	¾ hour rating	1	1200	1	2400
		2	900	2	1800
		3	600	3	1200
1990	¾ hour rating	1	1800	1	3600
		2	900	2	1800
		3	600	3	1200
	1 hour rating	1	2400	1	4800
		2	1200	2	2400
		3	800	3	1600
		NOT PERMITTED		4	1200
1995 to 2005	¾ hour rating	1	1800	1	5400
		2	900	2	2700
		3	600	3	1800
	1 hour rating	1	2400	1	7200
		2	1200	2	3600
		3	800	3	2400
		NOT PERMITTED		4	1800

A review of the area limitations in **Table 4** suggests that an increase in building area is permitted where:

- an automatic sprinkler system is provided throughout the entire building;
- a greater level of structural protection is provided;
- the number of storeys in building height is limited; and,
- the number of streets facing is increased.

The increase in building area where an automatic sprinkler is provided throughout the building was permitted to be twice as much as a building without sprinklers from the 1941 NBC to the 1990 NBC, and three times as much for the 1995 and 2005 editions of the NBC. The benefit of providing sprinkler protection and associated increase in building height and area will be discussed in more detail in the next section of this report.

Increasing the structural fire protection to 1-hour permitted an increase of 33% in building area from that required for ¾-hour protected construction. This was relevant to the 1953, and 1990 to 2005 editions of the NBC. The NBC recognized the benefit of passive fire protection in the form of fire separations. This was outlined in the 1995 Users' Guide, which states that[13]:

> *In smaller buildings of combustible construction, the most important consideration is that the occupants can vacate the building safely by means of protected egress paths. Provided all the occupants are safe, the fire department may decide that control of the fire spread to other buildings is an adequate response and that it will not be practicable to save the property itself after the occupants have left.*
>
> *By adding suitable protection to combustible framing, various levels of fire-resistance rating can be achieved. The NBC 1995 recognizes the use of protected wood framing having fire-resistance rating values of up to one hour.*

As outlined in the previous section of this report, an increase in building height is expected to pose an increased hazard to egress and fire fighting capability. Subsequently, as the height of a building increased, the allowable area was reduced, as shown in **Table 5**. The percentages are based on the allowable building area for a single storey having the same type of construction. The trend in the changes in base building area as the number of storeys is increased is by thirds, quarters or both. For the 1990 to 2005 editions of the NBC the allowable area was inversely proportional to the number of storeys in building height.

Table 5: Reduction in Building Area with Increased Building Height.

Construction	NBC	Height (Storeys)	Area (m^2)
Unprotected Wood Frame	1941	1	100%
		2	66%
Masonry and Wood frame	1941	1	100%
		2	66%
		3	66%
Heavy Timber	1941	1	100%
		2	66%
		3	66%
	1953	1	100%
		2	33%
		3	33%
		4	33%
¾ hour rating	1953	1	100%
		2	33%
	1960 to 1965	1	100%
		2	60%
		3	60%
	1970 to 1985	1	100%
		2	75%
		3	50%

Construction	NBC	Height (Storeys)	Area (m^2)
	1990 to 2005	1	100%
		2	50%
		3	33%
1 hour rating	1990 to 2005	1	100%
		2	50%
		3	33%
		4	25%

As shown in **Table 6**, it is important to note that other than for heavy timber construction in the 1941 NBC, the permitted building area for the maximum height of combustible construction allowed ranges between 500 and 800 m^2. The permitted building area from edition-to-edition of the NBC is consistent for ¾-hour protected construction, which remains at 500 to 600 m^2 from the 1941 NBC to the current edition. This area is consistent with that recommended by the NFPA Committee on Building Construction[12], and the survey of fire chiefs in the US[11].

Table 6: Building Area at Maximum Building Height.

Construction	NBC	Peak Height (Storeys)	Area (m^2)
Unprotected Wood Frame	1941	2	500
	1953	1	500
Masonry and Wood frame	1941	3	500
Heavy Timber	1941	4	1500
	1953	3	800
¾ hour rating	1953	2	600
	1960 to 2005	3	600
1 hour rating	1990 to 2005	3	800
		4	600*

* Corrected by dividing by sprinkler factor of 3 to get a baseline area

The changes in allowable building area from edition-to-edition of the NBC are shown in **Table 7** to **Table 9**, and are relatively minor. As shown in **Table 7**, the largest change occurs for protected construction with a structural fire protection rating of ¾-hour from the 1953 NBC to the 1960 NBC. The permitted area is almost reduced by half, but returns to what it was in the 1953 NBC by the 1990 NBC. The change in area permitted for a single storey of construction from the 1985 to the 1990 NBC brought the permitted area limitations in line with the intent that the allowable area was inversely proportional to the number of storeys permitted.

Table 7: Change in Building Area from Edition to Edition – 1 Storey.

Type of Construction	NBC	Area (m^2)
Unprotected Wood frame	1941 to 1953	750
Masonry and Wood frame	1941	750
Heavy Timber	1941	2250
	1953	2400
¾-hour rating	1953	1800
	1960 to 1965	1000
	1970 to 1985	1200
	1990 to 2005	1800

As shown in **Table 8**, for a building height of 2 storeys, the 1953 edition of the NBC reduced the area permitted for heavy timber to nearly half of that permitted in 1941. This is the most significant reduction in building area from one edition to another for 2 storeys. Protected construction with a structural fire protection rating of ¾-hour was not recognized for 2 storeys in building height until the 1953 NBC where the permitted area remained at 600 m^2 until the 1970 NBC where it was increased to 900 m^2 and remained unchanged until the current version (2005 NBC).

Table 8: Change in Building Area from Edition to Edition – 2 Storey.

Type of Construction	NBC Edition	Area (m^2)
Unprotected Wood frame	1941	500
Masonry and Wood frame	1941	500
Heavy Timber	1941	1500
	1953	800
¾-hour rating	1953 to 1965	600
	1970 to 2005	900

As shown in **Table 9**, for a building height of 3 storeys, the permitted building area varies for the different NBC editions as a function of construction type. The 1941 NBC only permitted 3 storeys in building height for masonry/wood frame and heavy timber construction, with three times the area permitted for heavy timber over masonry/wood frame. The 1953 edition of the NBC reduced the area permitted for heavy timber to nearly half of that permitted in 1941. Protected construction with a structural fire protection rating of ¾-hour was not recognized for 3 storeys in building height until the 1960 NBC where the permitted area remained unchanged at 600 m^2 until the current version (2005 NBC). Note that a structural fire protection rating 1-hour and 4 storeys in building height permits the same building area as the ¾-hour fire structural fire protection rating and 3 storeys in building height.

Table 9: Change in Building Area from Edition to Edition – 3 Storey.

Type of Construction	NBC Edition	Area (m^2)
Masonry and Wood frame	1941	500
Heavy Timber	1941	1500
	1953	800
¾-hour rating	1960 to 2005	600

The NBC assumes that each building faces at least one street. Where a building faces 2 or 3 streets, the area increase is permitted to be 1.25 and 1.5 times the base area respectively. These factors originate from earlier versions of the NBC and US model codes prior to the 1941 NBC and have applied to unsprinklered and sprinklered buildings alike up to the 1990 Edition of the NBC. A change between the 1990 and 1995 editions of the NBC removed the "streets facing" factor for sprinklered buildings, allowing all sprinklered buildings to be considered to have the same allowable area for a building facing three streets with the doubling of that area for sprinklering.

Considering all of the factors permitting an increase in building area for a combustible residential building, the following formula can be utilized to establish the allowable building area in the current (1995) NBC:

$$A = \left(\frac{1}{H}\right) \cdot A_B \cdot S \cdot SF \cdot CF$$

Where:

A = Building Area (m^2)
H = Building Height (Storeys)
A_B = Base Building Area (m^2)
S = Sprinkler Factor
SF = "Streets Facing" Factor
CF = Construction Factor

Base Building Area (A_B)

The base building area for combustible residential construction is 1800 m^2

Sprinkler Factor (S)

Unsprinklered = 1.00
Sprinklered = 2.00

Streets Facing Factor[b] (SF)

Facing 1 street = 1.00
Facing 2 streets = 1.25
Facing 3 streets = 1.50

Construction Factor (CF)

¾-hour fire rated structural components = 1.00
1-hour fire rated structural components = 1.33

[b] A factor of 1.50 should be applied if the building is sprinklered regardless of number of streets facing.

The trend in the 1941 NBC to 2005 NBC suggest that the allowable building areas have changed only slightly between editions of the NBC, with minimal difference from edition-to-edition for the highest permitted building height. The intent of limiting building heights and areas carries forward to today's codes as outlined in the Users' Guide to Part 3 of the 1995 NBC. Specifically[13]:

> *The NBC 1995 assumes that the higher the building or the larger the building area, the greater will be the problems of evacuation and of fire fighting. Hence, the requirements become more stringent as the building increases in height or area. On the other hand, the NBC 1995 assumes that when a building faces several streets from which the fire can be fought, or when a building is sprinklered, a lower value for structural fire protection is sufficient. The number of streets that a building faces is only relevant for buildings that are not sprinklered and are not more than six storeys in building height. Most fire fighting equipment cannot reach the upper storeys of higher buildings.*

3.3 SUMMARY

The historical rationale for limiting the height and area of buildings was to address safety to life and property where the greatest risk envisioned was conflagration. The limit to height and area for combustible residential construction was estimated to be 3 storeys with a building area of approximately 500 to 600 m^2 for an unsprinklered building, 4 storeys for a sprinklered building with an area 3 times the building area of an unsprinklered building. This is what was envisioned as reasonable based on early 1900's capabilities in:

- fire resistive construction in limiting fire growth and spread;
- fire resistive construction protecting egress facilities and distance required to travel to a point of safety outside of the building; and,
- fire fighting techniques and available equipment.

Since the early 1900's advances have occurred in building regulation, construction materials and techniques, effectiveness and reliability of fire alarm and sprinkler systems, and fire fighting tactics and equipment. These advances are reflected in the fire record, indicating a reduction of structure fires over the past century and the risk of conflagration significantly reduced. Consideration of these factors in light of current risks relative to fires in combustible wood frame buildings suggest a reassessment of the basis used to develop the height and area limitations in light of current construction techniques, materials and fire department capabilities.

4.0 QUESTION 2: SPRINKLERING

Question 2:

> *How has the building code, relative to the construction requirements for residential construction, adapted to recognize the benefits of sprinklering? And does sprinklering a residential building provide a new rationale for reconsidering the underlying assumptions affecting height and area of a building?*

The addition of sprinklers to a building currently allows for an increase in building area 3 times that for an unsprinklered building. The historical rationale for this increase spans over a century of considerations relative to sprinkler effectiveness in controlling the growth and spread of a fire. However, the increased allowance has been based on the experience and judgment of the code authors at the time of the changes, and has never been reconceptualized beyond its original basis to reflect a more modern understanding of burning behaviour, compartmentation, reliability of fire protection systems, and fire fighting capability.

Sprinklers were originally utilized to protect property with the intention of reducing insurance rates. Their effectiveness in limiting fire growth and spread was identified early on, but their importance to life safety was not recognized until the early 1900's. A handbook on sprinklers published in 1914 discussed the benefits of sprinklers to life safety[14]:

> *Up to a few years ago, sprinklers were more or less of an experiment but they have now been successfully used for 40 years and their efficiency can no longer be questioned. It is a noteworthy fact that in all the fires in sprinklered buildings, there has been practically no loss of life. In the Grover Shoe Factory fire in Brockton in 1907 it is true that several lives were lost but this was due primarily to the explosion of the boiler. In the Herald Building fire in Montreal in 1910, there was also a loss of life but this was due to the collapse of the building that preceded the fire. The records of the Factory Mutual Insurance Companies covering risks employing 1,500,000 people show only 12 deaths in sprinklered buildings in 38 years. Of these 3 were due to persons going back into a burning building to save property and 4 were firemen engaged in fighting the fire. There may be a few other isolated cases but they are so rare that they only go to prove the rule.*

Building code committees attempted to recognize the benefits of sprinklering by allowing relaxations of various requirements including, building height and area. However, the committees did not have enough technical information to quantify the benefit to life provided by sprinklers and often chose an arbitrary multiplication factor.

New York City recognized the benefit of sprinklers in a building ordinance for factory buildings, which suggested that[15]:

> *If a standard equipment of automatic sprinklers is installed throughout any building, the allowable floor area between fire walls may be greater by fifty per cent than those stated in this [ordinance].*

This factor was reconsidered by the NFPA Committee on Safety to Life who stated that:

> *The New York Law recognizes the value of sprinkler protection through a flat, Increase of 50 per cent in the number of persons who may be accommodated as determined by the available exits...Those of us who know sprinkler efficiency and the remarkable freedom from loss of life in sprinklered buildings feel that, this*

allowance might be doubled with safety-certainly as viewed comparatively. It is hoped that more and more legal recognition will be given the automatic sprinkler.

The Committee recommended a 100 per cent increase in the allowable number of occupants for sprinkler protection which increase from the former 50 percent has now been made by the New York Law.

The proceedings of the NFPA Twenty-Fifth Annual Meeting – Report of Committee on Building Construction[16], 1921 suggested an increase in area of 66 ⅔ percent for office buildings. A discussion at the committee meeting, demonstrating the arbitrary nature of applying a factor for sprinklering, suggests:

MR. BOONE: On the subject of area, 66 ⅔% increase, I note, is allowed where sprinklers are installed. I feel that in a sprinklered office building cut up in small sections, with numerous partitions on each floor, the area could be very materially increased. As a matter of fact, I have always held the opinion that considerations of area are almost blotted out by standard automatic sprinkler protection, and in view of this light occupancy in offices with small sections and numerous partitions, I thought that, perhaps, the area might be increased to more than 66 ⅔%, possibly 100%.

MR. WOOLSON: The, Chairman appreciates the significance of that criticism. May I ask if you make the suggestion of 100%?

MR. BOONE: I would make that suggestion as, a motion.

The motion was adopted.

No technical basis, other than what is written above, was provided to justify the increase from 66 ⅔% to 100% for building area where the building was sprinklered. The provision of an automatic sprinkler system for most occupancies in the US codes and NBC from this point forward allowed for an increase of 100% that permitted for a building without sprinklers. The NBC permitted a 100% increase in building area until the 1995 NBC, which permitted an increase of 200%.

An early version of the code change proposal to the 1985 NBC that permitted 4 storeys in building height for a combustible, unsprinklered residential building was based on the provision of 1-hour rated structural fire protection (sprinklers were not originally proposed). The basis for this change as indicated in the minutes of meetings of the Standing Committee on Fire Protection was as follows:

The NBC currently recognizes the safety of 1 hour rated construction for noncombustible buildings up to 6 storeys in building height and with areas ranging from 2000 m^2 for a 6 storey building to unlimited area for a 1 storey building.

In view of the fact that the basic tests for fire-resistance rating are not predicated on the type of construction but are performance based it is considered that the proposed change permitting combustible framing with equal fire-resistance rating but whose area would be approximately 20 percent of that for a noncombustible building is a conservative approach.

The model codes in the U.S.A. permit 4 storey residential buildings to be constructed with 1 hour rated wood frame construction. Studies of the fire death rate in multi-family residential buildings in the U.S.A. indicate that it is very low and that wood frame construction has not been identified as a problem.

A staff note at the end of the minutes for the proposed code change stated that there was not enough statistical information on fires in combustible construction to accept the change without the provision of sprinklers.

As outlined in the previous section of this report, a change between the 1990 and 1995 editions of the NBC removed the "streets facing" factor for sprinklered buildings, allowing all sprinklered buildings to have the same allowable area as permitted for a building facing three streets.

Sprinklering a residential building does not provide a new rationale for reconsidering the underlying assumptions affecting the height of a building. The original rationale was arbitrary, and not based on quantifiable scientific data. More recent changes to the NBC (1990 to 1995 editions) recognized the benefit of sprinklering by increasing the allowable building height from 3 to 4 storeys and allowing the building to be considered to be facing three streets (regardless of the actual number of streets facing). A new rationale for reconsidering the underlying height and area of a building should be based on an assessment of current sprinklering capabilities and statistics.

5.0 QUESTION 3: RELATION TO IBC

Question 3:

> *Is there a different rationale underlying the assumptions in the International Building Code (United States) vis-à-vis height and area compared to those in the BC Building Code and is it possible to use these IBC assumptions to reconsider the rationale for our height and area calculations?*

The first International Building Code (IBC) was published in 1997 after three years of research and development by the International Code Council (ICC). The IBC was patterned after the three legacy codes, the BOCA National Building Code (BOCA NBC), Uniform Building Code (UBC), and Standard Building Code (SBC), in existence in the US at the time of the development of the first IBC. When developing the height and area limitations in the IBC, the ICC recognized the differences in the three legacy codes at that time, and didn't want to limit the construction of future buildings to less than was permitted by any one of the legacy codes. Thus, the ICC combined the building height and area requirements from the three legacy codes by selecting the maximum values. These are the values in use today.

The height and area limitations in the three legacy codes have the same origins as those of the NBC, developed in larger US cities in the early 1900's. These origins were studied by the committees developing the IBC and a task group formed by the National Fire Protection Association with the intention of developing NFPA 5000, "Building Construction and Safety Code". These groups identified that the height and area tables in the three legacy codes were derived from the same base document or simply traditional acceptance and there was no compelling fire data to support limiting height or area of a building beyond the mechanical properties of construction materials[17]. Building area limitations for different occupancies were based on modified versions of what was considered a standard building where area modifiers were multiplied by the standard building area having no relevance to fire risk, other than what was considered to be reasonable at the time of their development. It was argued that:

> *height and area requirements were the result of good science and contemporary fire protection engineering. However, contrary to popular belief, there is no technical justification for limiting building areas based upon fire risk. Further, there are no statistics to support the efficacy of current limitations. Rather, modern equipment to detect and control fire growth, limited travel distance, and protected exits have provided surprisingly good property protection. They have also provided exceptionally good life safety.*

This statement is not completely accurate. As outlined for Question 1 in this report, building height and area limitations were based on the capabilities and perceived risk at the time of their development. Since that time, capabilities have increased and risk has decreased, and the committees have not had a comparable survey to reconsider the original basis

The committees developing NFPA 5000 came to a similar conclusion on the origins of the height and area limitations in the existing codes that the available information to support height and area limitations was controversial at best. The NFPA committee, made up of representatives of the construction industry, proposed creating a new form of the height and area limitations. However, they failed to achieve a member consensus on the matter and reverted to the conventional height and area limitations. Since that time a new approach to building height and area limitation has been implemented into the 2003 edition of NFPA 5000.

The current version of the IBC allows for an additional storey for combustible residential construction where the building is fully sprinklered, provided the building is no greater than 60 feet high. Above this height the building would be considered a "high building." Based on a conversation with a representative of the American Forest & Paper Association, the additional storey permitted for combustible residential construction is an artifact of the UBC based on a revision to the height and area requirements made by the City of Seattle in the 1970's. This revision was eventually incorporated into the UBC and ultimately into the IBC.

It is our understanding from a discussion with a representative from the City of Seattle that no real technical study was completed on the subject and was likely a result of the regulatory impact on buildings in "hilly" Seattle when Seattle transitioned from the Seattle Building Code to the UBC with Seattle amendments. Seattle incorporated the UBC definition of storey and dropped Seattle's definition of First Storey.

The additional storey of combustible construction is the most significant difference between the current IBC and BCBC for residential construction. However, other than the additional storey permitted, there is no difference underlying the assumptions in the International Building Code (IBC) vis-à-vis height and area compared to those in the BC Building Code that would allow for a reconsideration of the rationale for the height and area limitations. However, a statistical examination of the impact of the additional storey of building height in Seattle may provide a mechanism to establish whether risk associated with the additional storey has been increased.

6.0 DISCUSSION & SUMMARY

This report has outlined the basis and history of the requirements pertaining to building height and area requirements for combustible residential construction in the current edition of the British Columbia Building Code (2006 Edition), based on three questions:

1. What is the historical rationale for limiting the height and area of combustible residential construction to 3 storeys for an unsprinklered building and 4 storeys for a sprinklered building?
2. How has the building code, relative to the construction requirements for residential construction, adapted to recognize the benefits of sprinklering? And does sprinklering a residential building provide a new rationale for reconsidering the underlying assumptions affecting height and area of a building?
3. Is there a different rationale underlying the assumptions in the International Building Code (United States) vis-à-vis height and area compared to those in the BC Building Code and is it possible to use these IBC assumptions to reconsider the rationale for our height and area calculations?

The historical rationale for limiting the height and area of combustible residential construction to 3 storeys for an unsprinklered building and 4 storeys for a sprinklered building is based on an examination of risk and capability from the early 1900's. Advances in building regulation, construction materials and techniques, fire protection/detection and fire fighting techniques and equipment in addition to our current understanding of fire development and people behaviour provide a mechanism for re-examining fire risk associated with combustible residential construction and capabilities in mitigating that risk.

Sprinklering has permitted both an increase in building height for combustible residential construction and an increase in area. However, this increase has been based on simplified multiplication factors, with the most significant increase occurring in the 1990 and 1995 versions of the NBC allowing an additional storey of building height and tripled base building area. Early consideration of the protection afforded by sprinklers was made within the context of their effectiveness in factories and warehouses, where compartmentation was limited. Given:

- the changes in sprinkler technology and reliability;
- the larger pool of available sprinkler statistics;
- better understanding on theory and testing of sprinkler capabilities to control and suppress fires; and,
- increases in building compartmentation.

the benefit of sprinkler protection should be reconsidered relative to the underlying assumptions affecting height and area of a building.

A sprinkler system is an active fire protection system, expected to respond to a fire event. Passive fire protection (i.e., fire separation) does not require a specific response in order to achieve its objective. Active systems can fail to respond as intended due to poor installation or maintenance. Passive systems can fail to achieve their objective where installed inappropriately or compromised by installation of building services after occupancy of a building. A balance of both types of system help increase the reliability of a building in limiting growth and spread of fire.

Compartmentation was identified in early studies as an important consideration relative to the spread of fire and subsequently in the development of the height and area limitations, and was touched on at various points in the historical development of the US and Canadian codes[8,9,13,16]. The NBC has more recently recognized the benefit of compartmentation by allowing an increase in building height and area where a building is provided with 1-hour protected construction. However, the increase was an arbitrary estimation of the protection afforded by the increase in the fire rating.

The effects of compartmentation have not been studied recently within the context of revisiting building height and area limitations given new construction materials and methodologies, which have changed significantly over the past 100 years. These advances in compartmentation raise the question of what is the difference between a combustible and a noncombustile structural element (column, beam, floor assembly) having the same fire-resistance rating? If they pass the same test standard for fire endurance, does the combustible construction provide a greater level of risk?

The assumptions underlying the rationale for limiting building height and area in the International Building Code are the same as those in the BC Building Code. Changes to the UBC based on City of Seattle amendments and subsequently changes to the IBC incorporating these requirements have allowed for an additional storey in height for combustible residential construction. An examination of the fire statistics in Seattle may provide a mechanism to establish whether risk associated with the additional storey has been increased.

The underlying answer to all of these questions is a re-evaluation of risk and capability: what is the current risk to life and property and what are the current capabilities in dealing with the risk. The basis for the height and area limitations in the 2006 BCBC were developed nearly 100 years ago when city conflagration or large life loss were prominent considerations. The means for dealing with these risks, in part, was to limit the height and area of buildings to what the fire department of the time could reasonably handle. The statistical fire record has shown that the number of fires is decreasing, loss of life in fires has decreased, and the relationship of city-wide conflagrations to interior building design is not correlated in a reasonable way to building height and area.

In summary, there is a lack of definition to correlate the building area and height to the overall construction, compartmentation, and fire and life safety systems. The process can be summarized as follows:

- Building area and heights were based on a survey of fire services capabilities in the early 19th century. During this era,
    - The methods of construction were vastly different and methods of determining fire-resistance of structures were in their infancy.
    - The degree of building compartmentation that was factored into the reviews is not representative of residential construction in today's code.
    - Interior finishes were less controlled and flame-spread concepts were in their infancy. Wood was a more predominant ceiling finish, whereas gypsum board is a more common material for walls and ceilings in residences today.
    - Exiting, fire alarm systems, and evacuation plans were less regulated and less effective. Concepts on evacuation relative to building height were based on buildings with open or unprotected stairs and not fire separated stair shafts as required by today's codes.

  - The behaviour of people during a fire had not been studied and was therefore not understood.
  - To the extent that it exists today, fire services did not have breathing apparatus, fire fighter's stairs, aerial ladder trucks, addressable fire alarm systems, and floor plans. Hence, the building area and height rationalization based on hose stream penetration is not representative of today's capabilities.

- Over time, the NBC was revised to adapt to different formats, and, only in the later editions of the code was it modified based on fire research. However, the modifications were incremental and today's BCBC still coincides with the premise from early 1900's relative to allowable building height and area.
- Although the compartmentation of a building into several fire compartments was recognized to reduce fire development, its correlation to height and area was never fully addressed. The height and area requirements are essentially premised on the building being one fire compartment.
- The capabilities in analyzing overall fire growth and spread using test data, empirical correlations, and modern computer tools is not factored into methods of considering compartmentation relative to building height and area.
- Building height and area can be better correlated in a risk-based context using performance-based methodologies that address the potential fire development scenarios for a building. In buildings of combustible construction, this would include fires in a floor area, concealed spaces, and exterior to the building.

7.0 FUTURE RESEARCH

The following future research considerations are suggested based on the review summarized in this report:

- Examine fire statistics in combustible wood framed residential structures for sprinklered and unsprinklered buildings.
- Survey fire departments to establish capabilities.
- Review research relative to contribution of combustible wood framing in fire separations to the total energy.
- Examine height and area limitations and their historical basis in European Codes.
- Examine height and area limitations for noncombustible construction and other occupancies, particularly the use of unprotected steel where for the same building a ¾-hour fire resistance-rating would be required for combustible construction.

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